# COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

## "Dual-Use and Manufacturability"

**Short Term Project (STP) #20**

**FINAL TECHNICAL REPORT**
**Results and Accomplishments (August 1994 through July 1995)**
**Report No. CRAMTD STP #20 - FTR14.0**
**CDRL Sequence A004**
**March 1996**

CRAMTD CONTRACT NO. DLA900-88-D-0383
CLIN 0003

Sponsored by:
DEFENSE LOGISTICS AGENCY
8725 John J. Kingman Road
Ft. Belvoir, VA 22060-6221

Contractor:
Rutgers, The State University of New Jersey
THE CENTER FOR ADVANCED FOOD TECHNOLOGY*
Cook College
N.J. Agricultural Experiment Station
New Brunswick, New Jersey 08903

Principal Investigators:
E.A. Elsayed and H. Bruins

Dr. John F. Coburn
Program Director

TEL: 908-445-6132
FAX: 908-445-6145





*A New Jersey Commission on Science and Technology Center

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
March 1996

**3. REPORT TYPE AND DATES COVERED**
Final Aug 1994 - Jul 1995

**4. TITLE AND SUBTITLE**
Dual-Use and Manufacturability
(Short Term Project - STP#20)

**5. FUNDING NUMBERS**
C-DLA900-88D-0383
PE-7811s
PR-88003

**6. AUTHOR(S)**
E.A. Elsayed and H. Bruins

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Rutgers, The State University of New Jersey
The Center for Advanced Food Technology
Cook College, NJ Agricultural Experiment Station
New Brunswick, NJ 08903

**8. PERFORMING ORGANIZATION REPORT NUMBER**
FTR 14.0

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Defense Logistics Agency
8725 John J. Kingman Road
Ft. Belvoir, VA 22060-6221

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

Following literature review, investigation of potential MRE/Dual-Use products, processing capabilities, and measurement of product/process interactions, a producibility index was developed that includes process capability and manufacturing cost. The process capability index component compares the quality of the produced products against the specification limits of the product to obtain an assessment of the process performance in producing consistent product quality. A cost analysis model, using commercially available spreadsheet software, of an MRE producing facility was developed that can be used to analyze the financial impact of various process option/configurations on the manufacturing cost of an MRE. This model provides the manufacturing cost input to the overall producibility index. Finally, the use of the producibility index was demonstrated in five case studies including Beef Stew and Ham Slice. In support of enabling the computation and use of manufacturability/ producibility indicies, including the methodology for collecting the necessary data, it is recommended that a next generation of computer software tools be developed.

**14. SUBJECT TERMS**

**15. NUMBER OF PAGES**
122

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

# Contents

# 1.0 CRAMTD STP #20
# Results and Accomplishments

## 1.1 Introduction and Background

STP#20 started September 1, 1994 based on technical and cost proposals dated May 26, 1994 that were submitted to the DLA on May 31, 1994. Final approval for the project was received on August 30, 1994. The broad objective of the project was to develop and demonstrate a method for quantifying the manufacturability of products on food product filling and packaging systems and the flexibility of dual-use manufacturing. Indices were to be developed for manufacturability considering such factors as specification, production rate and product quality. Manufacturing characterization would support capital investment decisions leading to optimum flexibility and overlap with targeted products. Due to the time available, the scope was limited to MRE but can later be extended to Tray-Packs.

The military services express a need to make changes in the menu of combat rations (MRE) to minimize boredom among the soldiers who need to eat them. At present, the planned rate is about two entree items per year. The current growing requirement for using placeable food items instead of casserole items in MRE pouches is causing a significant change in the capital equipment needed. Changing from mechanically pumping food to individually placing relatively large items, such as smokey franks or chicken breasts requires a significant change in the kind of filling and packaging equipment that must be used. CRAMTD identified the horizontal form/fill/seal (HFFS) technology as an alternate packaging system with better capability to handle placeable type products. This project is to support assessment of potential MRE products as most suitable for this HFFS technology, and which are more difficult to manufacture. To make this assessment, a producibility index needs to be developed which measures the relative ease of manufacturing a product. Manufacturability measurement, in terms of a producibility index, is an essential part in the design process to determine the probability of successfully producing the product in terms of production rate, quality of final product, and the cost of production.

As described in STP #3, "Generic Inspection - Statistical Process Control System for a Combat Ration Manufacturing Facility" in the analysis of advanced process control strategies, if a process is poorly designed or the product has low producibility, the statistical parameters included in SPC control will be of little avail toward producing the desired quality. One of the objectives of STP #20 is to develop a measure of the ability of a food manufacturing process to produce products within a specified quality range.

## 1.2 Results and Conclusions

Following a literature search, investigation of potential MRE/Dual-Use products, processing capabilities, and measurement of product/process interactions, a producibility index was developed that includes process capability and manufacturing cost. The process capability index

component compares the quality of the produced products against the specification limits of the product to obtain an assessment of the process performance in producing consistent product quality. It, therefore, fulfills the objective of supporting Statistical Process Control in manufacturing quality management.

A cost analysis model, using commercially available spreadsheet software, of an MRE producing facility was developed that can be used to analyze the financial impact of various process option/configurations on the manufacturing cost of an MRE. This model provides the manufacturing cost input to the overall producibility index. Further, a systems dynamics model was developed to provide a visualization of the relationships between the various cost facets.

Finally the use of the producibility index was demonstrated in five case studies including Beef Stew and Ham Slice. The methodology and results are documented in Technical Working Paper (TWP) 106, "A Producibility Index with Process Capability and Manufacturing Cost", and are summarized in this Final Technical Report.

## 1.3 Recommendations

The concepts and methods developed in this STP should be broadly communicated so that manufacturers, process designers, and product specifiers more clearly understand and appreciate the role and interactions necessary to control cost and product quality. In addition to the distribution of TWP #106 "A Producibility Index with Process Capability and Manufacturing Cost", it is proposed that a Workshop be held to introduce the subject. Technical presentations at Food Engineering and Manufacturing forums such as the Institute of Food Technologists (IFT) are also important to wide acceptance of the concepts. Technical presentations, including technical publications in Journals, allow peer review to sharpen, endorse and promulgate the technology.

In support of enabling the computation and use of manufacturability/producibility indicies, including the methodology for collecting the necessary data, it is recommended that a next generation of computer software tools be developed. The mathematics, lookup tables, and spreadsheets should all be integrated in order to facilitate use of the concepts. A generalized manual should also be developed to guide the practitioner through the requisite process/product analysis and data collection.

# 2.0 Program Management

STP #20 was a two-phase work activity. The two phases had the following general objectives:

**Phase I** Develop a manufacturability index which includes equipment performance, product and process interactions, and manufacturing cost.

**Phase II** Recommend and demonstrate the manufacturability of a selected product and recommend how manufacturability of product/process can be improved.

Phase I was to begin with Literature, Equipment and Product Surveys and if no existing manufacturability index was found for food products, an adaptation was to be made from indices that were developed for discrete parts manufacture. Investment analysis was to be included in the assessment of manufacturability. Based on the information gathered and the methodology developed, Phase II was to demonstrate the manufacturability determination for one or more products. The work activity and status are illustrated on the attached Figure 1, CRAMTD STP#20 "Dual-Use and Manufacturability", Time and Event Milestones (Appendix 4.1).

## 2.1 Summary of STP Accomplishments

- The results of a literature survey indicated that no manufacturability index was ever developed for food product packaging.
- In cooperation with the U.S. Army Natick Research, Development and Engineering Center, a list of 28 MRE Entrees were identified for evaluation of their manufacturability.
- Virtual or Distributed Manufacturing was proposed as a concept to increase production capacity for MRE pouches and to lower cost.
- Potential MRE/Dual-Use entree items (Beef Burritos, Chicken Wings, Franfurters, Beef Steaks and Beef Stew) were evaluated.
- A piston filler nozzle, specifically designed for products such as beef stew, was used to quantify variability in net and drain weights.
- A method for determining the "fit" or "match" of product/process or process/process was developed.
- A producibility index was developed that includes evaluation of process capability, production rate, and manufacturing cost.
- A process capability index was defined which compares the variability of the quality distribution against the specification limits of the product.
- A financial model for an MRE producing facility was developed using commercially available spreadsheet software.
- A cost model was developed to demonstrate and provide visualization of the

relationship between the various cost facets of a manufacturing process.

- The use of the producibility index was demonstrated based on experiments on the MRE line with Beef Stew and Ham Slices
- Technical Working Paper (TWP) 106 "A Producibility Index with Process Capability and Manufacuring Cost" was written and distributed.
- The concept of the producibility index and its impact on statistical process control was described at the January 10, 1996 "MRE Quality Working Group" meeting in Cincinnati.

# 3.0 Short Term Project Activities

## 3.1 STP Phase I Task

### 3.1.1 Literature Survey (Task 4.3.1.1)

A literature survey was conducted and the results indicated that no index of manufacturability has ever been developed for food product packaging. The preliminary results of the literature survey were presented at the annual Fall Meeting of the R&D Associates and released as technical working paper, TWP 96, "Capability and Manufacturability Measures". Technical working paper TWP 106, "A Producibility Index with Process Capability and Manufacturing Cost" (Appendix 4.2) extends and summarizes those findings in its Introduction.

Among various types of production systems, the manufacturing/assembly industry appears to be the first to pioneer the implementation of the design-production integration concept. Bolz (1977) provides the design principles that help to improve the designed product's producibility in terms of machining processes. These design principles are later developed into a concept called "Design For Manufacturability (DFM)" and "Design For Assembly(DFA)". *However, the DFM and DFA approaches are specifically focused on the physical aspects of manufacturability and assemblability and largely ignore the process/product interaction as related to the product quality.*

Harry and Lawson (1992) appear to be the first to pioneer producibility research by looking at the process capability. Their work is later included in "Producibility Measurement Guidelines" by the Department of Navy. In Harry and Lawson's work, the calculation procedures for evaluating the process capability have been very carefully crafted. *However, they do not include many concerns that we believe should be addressed in evaluating product producibility, specifically: quality characterizations, production capacity, and manufacturing cost.*

### 3.1.2 Equipment and Product Survey (Task 4.3.1.2)

#### 3.1.2.1 Products Survey

In cooperation with the US Army Natick Research, Development and Engineering Center, a list of 28 MRE Meals were identified for consideration in the evaluation of manufacturability. These meals represent either meals that were contracted for during the past five years or are being

considered for a contract in the next three years (Appendix 4.3).

#### 3.1.2.2 Equipment Survey

In general, the filling equipment for the MRE menu items can be divided into two categories: placeable items and pumpable items. Potential filling equipment was identified during the Pack Expo in Chicago on November 13 through 17, 1994 for the dual use type products that were being considered in this STP. A significant study of filling equipment was conducted during the execution of STP #2, "Filling Systems" (see Final Technical Report STP #2 - FTR 8.0). As universal feed systems, the robot for placeable products and the piston type filler for pumpable products were identified. Other filling equipment is available for products such as frankfurters but are too product specific.

To assess the dual use capability of the food industry in the U.S., assistance was requested of several providers of horizontal form/fill/seal machines and several retort manufacturers. The survey (Appendix 4.4) was aimed at determining the number of operational units and the general usage. Unfortunately, only one manufacturer responded and therefore no summary or conclusions were drawn. The lack of response is attributed to a concern in disclosing market share of equipment sales (considered proprietary information).

#### 3.1.2.3 Virtual or Distributed Manufacturing

Horizontal form/fill/seal equipment is extensively used in the meat packaging industry. Clear evidence of this can be seen in the supermarket were sliced meat products and prepared meats such as hot dogs and sausages are packed in HFFS containers. Most meat packaging plants pack products under refrigerated temperatures and distribute them under the same conditions. Most meat packaging plants, however, have no retort capability, and would require significant capital to become a producer of shelf stable food products.

On the other hand, the producers who manufacture shelf stable food products don't have the meat preparation capability and buy the meat products from the meat packers, either frozen or refrigerated, and repack into retortable containers.

The concept proposed is for meat packers to directly pack the product in a retortable container (e.g. MRE pouch). This product would then be packed in carboard boxes and shipped under refrigerated condition to a thermal processing facility. The product would be maintained at an internal temperature of 28 to 40F at all times until it is loaded into retorts at the thermal processing facility. Maximum time from packaging to retort loading can be 72 hours. The product has to be in the retort process within 2 hours after it leaves the refrigerated environment.

This concept would increase the production capacity for MRE pouches dramatically, without major capital investment from the government. A potential exists for lower cost product to the government. A meat packing operation has adequate facilities to rework product. In the case of ham slice production, the end pieces don't meet military specifications and cannot be packed. A meat packer would regrind these ham pieces and blend them into the next batch.

There are issues that need to be resolved in order for this concept to become a reality:

1. Is the concept agreeable to the USDA and the regulations that govern the thermal

processing industry?

2. Under whose USDA stamp would the product be distributed?

### 3.1.3 Development of Producibility Index (4.3.1.3)

#### 3.1.3.1 Product Characterization

To test the manufacturability of a range of products, potential MRE/Dual-Use entree items (Beef Burritos, Chicken Wings, Frankfurters and Beef Stew) were evaluated in the CRAMTD plant. It was observed that the MRE packaging material is sensitive to "defined" objects, such as chicken drumsticks. Under high vacuum the pouch will stretch around these objects and possibly lead to a film failure. Beef Stew was evaluated as a model pumpable product, and capability studies were conducted to quantify the performance of various pumping systems.

The evaluation of potential MRE/Dual Use entree items was continued by evaluating the packaging of commercially available Beef Steaks. As was observed earlier, the MRE packaging material is sensitive to "defined" objects. In this case, the ice crystals on the surface of frozen beef steaks damaged the film, leading to the conclusion that these products need to be at least defrosted on the surface prior to packaging.

#### 3.1.3.2 Process Capability

Emphasis was also placed on characterizing the capability index of a piston filler for pumpable product, such as beef stew. For this purpose, a plug nozzle specifically designed for such products was rented and experiments executed to quantify the variability in net weight, component weights and drain weight.

Four different measures of Process Capability are possible of which $C_p$ is shown below (see TWP 106 for a complete discription of this as well as the other measures). $C_p$ is appropriate for those processes that can be adjusted to meet the target value and where is distribution is normal:

$$C_p = \frac{USL-LSL}{6\sigma}$$

USL and LSL are the upper and lower specification limits respectively and the difference between them constitutes the tolerance for the quality characteristic being produced. Sigma, $\sigma$, is the standard deviation in the quality characteristic for the units produced by the available equipment. In order to obtain a high process capability index, one would like to see a high value for the tolerance (i.e., wide range of quality characteristic acceptability) and a low value for process standard deviation (i.e., well controlled process).

In the summary table below, a comparison of process capabilities is shown for two nozzles, standard and plug, and for manual filling. Process capability correlated with the standard deviation of the net fill weight ($C_p$ assumes that the mean can be adjusted).

Table 3.1.3.2 Process Capability of Filling Beef Stew, Summary

| Filler | Average Fill Weight | Std. Dev. | Cp |
|---|---|---|---|
| Standard Nozzle | 222.8 g | 5.23 | 0.89 |
| Plug Nozzle | 207.5 | 3.58 | 1.3 |
| Manual Fill | 233.8 | 3.09 | 1.5 |

### 3.1.3.3 Product/Process Measurements

Manufacturability of a product is a function of multiple "process" factors, such as packaging system, filling system, and the interactions between product and package. To quantify the manufacturability of a product/process system various "measurements" have to be conducted that relate the above system configuration to process efficiency, product yield, manufacturing cost, and other qualitative factors. One procedure has been developed to define the volume of the formed pouch and compare it to the volume of the product fill, with their respective standard deviations. The form of the Process Capability for "one-sided tail" comparisons $C_{pk}$ is:

$$C_{pk} = \frac{ContainerVolume - ProductVolume}{3\sigma}$$

Sigma, σ, is the estimated standard deviation for the difference in container and product volumes:

$$\sigma = \sqrt{(\sigma_{cnt}^2 + \sigma_{prd}^2)}$$

Using the standard deviations reported for section 3.1.3.2 filling but with a mean fill volume of 230cc for each filler plus a reserve container space of 65cc, and the pouch design volumes and standard deviations from TWP 106 (summarized in Table 3.1.3.3.a), the $C_{pk}$ for the

combinations are shown in Table 3.1.3.3.b.

Table 3.1.3.3.a Pouch Volumes from TWP 106

| Design | Pouch Film | Form Press. | Mean Vol. | Std Dev. |
|---|---|---|---|---|
| Pouch A | Reynolds | 18 psi | 261.5cc | 5.80 |
| Pouch B | Reynolds | 22 | 318.0 | 7.89 |
| Pouch C | Aluswiss | 27 | 330.6 | 5.83 |
| Pouch D | Aluswiss | 24 | 306.5 | 5.30 |

Table 3.1.3.3.b Product/Process "fit", $C_{pk}$.

| Pouch | Standard Nozzle | Plug Nozzle | Manual Fill |
|---|---|---|---|
| Pouch A | -1.407 | -1.622 | -1.686 |
| Pouch B | 0.801 | 0.880 | 0.901 |
| Pouch C | 1.491 | 1.718 | 1.784 |
| Pouch D | 0.506 | 0.593 | 0.619 |

Given the volume of Pouch A along with the reserve space, none of the Pouch A product fills "fit" ($C_{pk}$ is negative). The other combinations do "fit". The rank order based on pouch volume is that associated with standard deviation rather than mean volume. Similarly, the order associated with filling is that based on standard deviation (but in the example shown the mean volume of fill was assumed to be the same).

In the above example, other variables such as particle size, density and viscosity were not taken into account. As a result, the actual values shown are not transferrable to other products. The subject of Product/Process Measurements and "fits" will continue to be explored.

### 3.1.2.4 Producibility Index

Following the evaluations of process capability and manufacturing cost a producibility index is proposed that includes these two evaluations.

The producibility index (PI) proposed has the following form:

$$PI=[PCI_{critical}, PCI_{major}, PCI_{minor}, PCI_{average}, MC].$$

This index takes into account the critical, major, and minor characteristics of the product, and the manufacturing cost (MC). Sensitivity studies helped in selecting the most adequate index to be used. The geometric mean is more sensitive to small values than the arithmetic mean. This is desireable because a smaller PCI value diminishes producibility considerably. A value of zero will result in a zero geometric mean regardless of how high other values are. This is also desireable since a process with a PCI value of zero for any one characteristic is considered absolutely unacceptable regardless of the quality level of other characteristics.

**Process Capability Indices (PCI)**

The Process Capability Index (PCI) is chosen instead of the more traditional measure, quality yield, because the modern quality control concept is no longer satisfied by the quality yield via intensive inspection efforts. "Yield" is simply a measure that indicates the percentage of the products produced that passes the tolerance gauge or meets the specifications. In contrast, PCI is an index that indicates the consistency of the product quality. It compares the variability of the quality distribution against the specification limits of the product to obtain a fair view of the process performance in producing consistent product quality.

As stated earlier (see discussion of Process Capability above and TWP 106), four different measures of the PCI are possible of which $C_p$ is appropriate for those processes that can be adjusted to meet the target value and where the distribution is normal.

**Manufacturing Cost Estimate (MC)**

To estimate the manufacturing cost, the major elements taken into account were: production and schedule efficiency, raw materials, personnel, capital and equipment, and utilities. The values for MC are $/unit. These elements are described and their computation demonstrated in TWP 106. They are presented as a guideline for manufacturing cost estimation but not the only elements to be considered. Practitioners should develop their own manufacturing costs based on their particular stiuation.

### 3.1.4 Investment Analysis (4.3.1.4)

A cost model of an MRE producing facility was developed that can be used to analyze the financial impact of various process options/configurations on the manufacturing cost of an MRE. The intent is that this model be used in conjunction with Non-traditional Capital Investment Criteria, which will be used to quantify the more subjective benefits of certain process configurations. This cost model was built within a spreadsheet software package and takes into account process factors such as line speed, line efficiency, product yield, labor cost, utility cost, raw material cost and capital investments. These models are demonstrated in TWP 106, see for example: page 34 and its appendix D for "Manufacturing Cost Analysis for Pouch Forming Design", page 38 and its appendix F for "Producibility Indices for Different Designs of the Target Fill Weight", and page 43 and its appendix G for "Producibility Index for the Ham Slice Pouches".

To visualize and demonstrate the relationships between various cost facets of a

manufacturing process, the same cost model was developed using "ithink" (High Performance Systems, Inc.) systems dynamics simulation software. The Systems Dynamics model is described in TWP 106, page 34 and its appendix E, "Visual Representation: Cost Analysis for Beef Stew Pouches".

## 3.2 STP Phase II Task

### 3.2.1 Demonstration (Task 4.3.2.1)

In order to demonstrate the use of the developed producibility indices, experiments were conducted on the MRE line to produce Beef Stew and Ham Slices in MRE pouches under various product and process conditions. Data from these experiments are used as examples to demonstrate the use of the producibility index that was developed under this project (see attached TWP 106).

These experiments were targeted at demonstrating the application of the producibility index and did not include any adjustments in order to: a) optimize pouch forming (Pouch Forming Designs) nor b) optimize robot performance (Ham Slice Pouch). Conclusions drawn from these examples are, therefore, limited to the technologies as demonstrated in these experiments and not to the potential performance or even to our projected performance.

The cases used in the demonstration of Producibility Indices consisted of:

A. Process/Product Design for Beef Stew MRE Pouches
    1. Pouch Forming Designs & Film
    2. Target Fill Weights

B. Ham Slice MRE Pouches
    1. Hand Fill vs Robot Fill
    2. Automatic Slicing vs Automatic Slicing/Sizing.

### 3.2.2 Technical Guidance (4.3.2.2)

The Technical Working Paper TWP 106 "A Producibility Index with Process Capability and Manufacturing Cost" reviews current approaches to the assessment of product producibility and then developes and validates a methodology that quantifies the producibility of a product as it relates to its design characteristics. This TWP has been distributed as requested in response to the CRAMTD Abstract/Order Form.

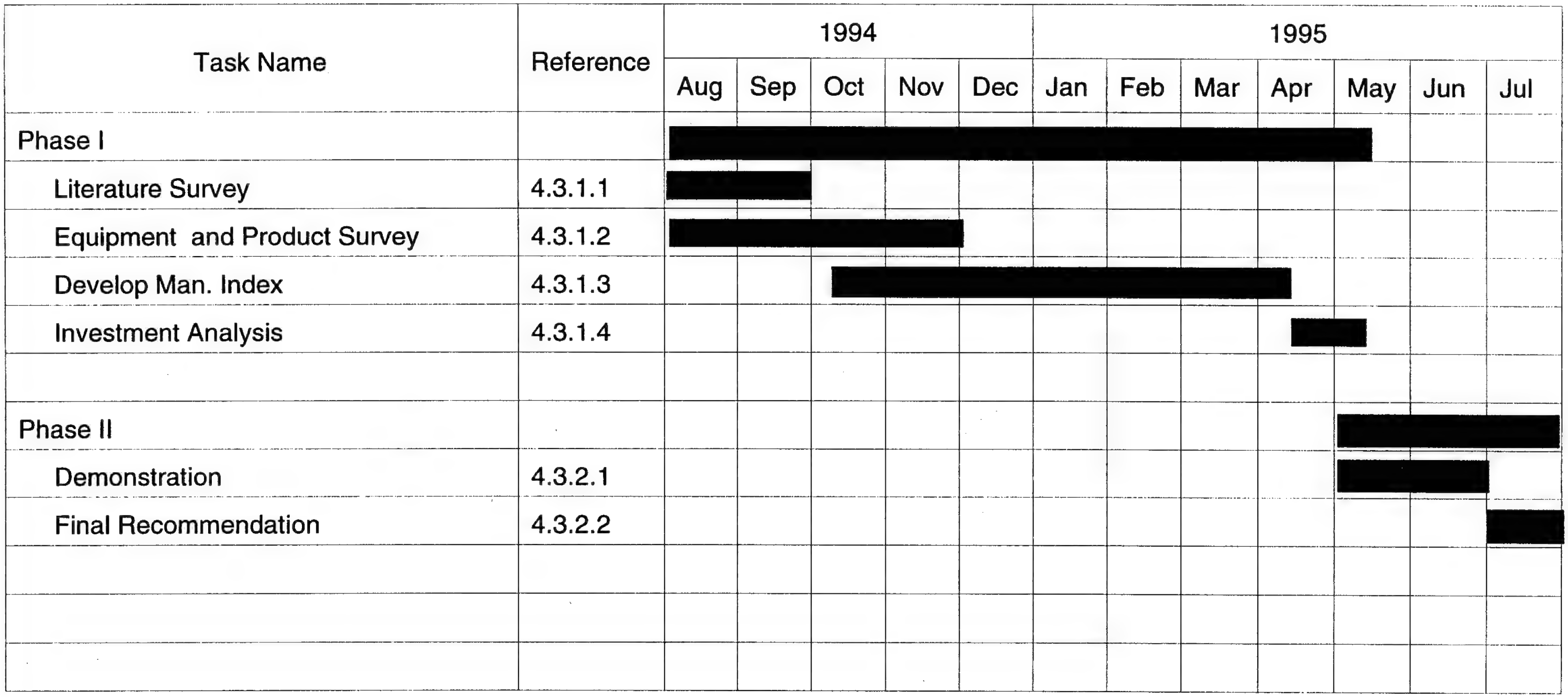
The concept and its impact on Statistical Process Control was described at the January 10, 1996 "MRE Quality Working Group" meeting in Cincinnati.

The concepts and methods developed in this STP should be broadly communicated so that manufacturers, process designers, and product specifiers more clearly understand and appreciate the role and interactions necessary to controlled cost and quality product. In addition to the

distribution of TWP #106 "A Producibility Index with Process Capability and Manufacturing Cost", it is proposed that a Workshop be held to introduce the subject. Technical presentations at Food Engineering and Manufacturing forums such as the Institute of Food Technologists (IFT) are also important to wide acceptance of the concepts. Technical presentations, including technical publications in Journals, allow peer review to sharpen, endorse and promulgate the technology.

# 4.0 Appendix

**Figure 1 - CRAMTD Short Term Project #20**
**Dual-Use and Manufacturability**
**Projected Time & Events and Milestones**




Printed: 02/22/96

CENTER FOR ADVANCED FOOD TECHNOLOGY
FOOD MANUFACTURING TECHNOLOGY FACILITY • 120 NEW ENGLAND AVENUE • PISCATAWAY • NEW JERSEY 08854

The folowing information was supplied by US. Army Natick Research, Development & Engineering Center on September 16, 1994

Products have been contracted for during the past four years (1991-1994):

| | |
|---|---|
| MIL-B-44059 | Beef Stew |
| MIL-C-44209 | Chicken Stew |
| MIL-C-44210 | Chicken with Rice |
| MIL-C-44204 | Corned Beef Hash |
| MIL-E-44200 | Escalloped Potatoes with Ham |
| MIL-F-44062 | Frankfurters |
| MIL-H-44063 | Ham Slice |
| MIL-O-44202 | Omelet with Ham |
| MIL-P-44432 | Pork Chow Mein |
| MIL-P-44201 | Pork with Rice |
| MIL-S-44205 | Spaghetti |
| MIL-T-44208 | Tuna with Noodles |

Proposed MRE Entree items for 1995 and 1996 are:

| | |
|---|---|
| CID-A-A-20209 | Beefsteak, grilled |
| MIL-B-44059 | Beef Stew |
| CID-A-A-20207 | Cheese Tortellini in Tomato Sauce |
| Draft CID | Chicken Parmesan |
| Draft MIL Spec | Chicken Patty, Grilled |
| MIL-C-44209 | Chicken with Rice |
| MIL-C-44207 | Chili and Macaroni |
| MIL-E-44200 | Escalloped Potatoes with Ham |
| MIL-F-44062 | Frankfurters |
| MIL-H-44063 | Ham Slice |
| CID-A-A-20204 | Pasta with Vegetables in Tomato Sauce |
| MIL-P-44432 | Pork Chow Mein |
| MIL-P-44201 | Pork with Rice |
| MIL-S-44205 | Spaghetti |
| MIL-T-44208 | Tuna with Noodles |

MRE Developmental Items (no specification number assigned)

Beef Burrito
Biscuit
Corn Bread
Eggs, Hard-Poached
Fruit Chew Bar
Macaroni and Cheese
Pizza
Pork Rib in BBQ Sauce
Rice Pilaf
Waffles

CENTER FOR ADVANCED FOOD TECHNOLOGY
FOOD MANUFACTURING TECHNOLOGY FACILITY • 120 NEW ENGLAND AVENUE • PISCATAWAY • NEW JERSEY 08854

# Equipment Data Base:

Under a contract with the Department of Defense, we need to assess the industrial capability of the food industry to produce combat ration products. To the best of our knowledge, your equipment is used or can be used in the production process of combat ration products. We would appreciate your cooperation in answering the questions below to the best of your knowledge

Equipment Vendor: ______________________

Name of Contact: ______________________

Title: ______________________

Address: ______________________

City ____________ State: ____ Zip: _____

Telephone: ____________ Fax: ____________

---

Type of equipment used for filling / primary packaging / sterilization of entree items. Please indicate also how many units are operational in the food industry.

| | Type | # Operational |
|---|---|---|
| 1) | ____________ | ________ |
| 2) | ____________ | ________ |
| 3) | ____________ | ________ |

Break down of usage by type equipment

| | 1 | 2 | 3 |
|---|---|---|---|
| Prepared Foods (dinners/meals/entrees) | _____ % | _____ % | _____ % |
| Prepared Meat, Poultry, Seafood | _____ % | _____ % | _____ % |
| Fruits and Vegetable Processing | _____ % | _____ % | _____ % |
| Bakery (fresh, refrigerated and frozen) | _____ % | _____ % | _____ % |
| Dairy/Beverage | _____ % | _____ % | _____ % |

**Note:** The information supplied on this form will be shared with our contractor, the Department of Defense

# COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

## A Producibility Index with Process Capability and Manfacturing Cost

**Technical Working Paper (TWP) 106**

**E.A. Elsayed, H.B. Bruins, and A. Chen**

**September 1995**

Sponsored by:
DEFENSE LOGISTICS AGENCY
Cameron Station
Alexandria, VA 22304-6145

Contractor:
Rutgers, The State University of New Jersey
THE CENTER FOR ADVANCED FOOD TECHNOLOGY*
Cook College
N.J. Agricultural Experiment Station
New Brunswick, New Jersey 08903

Dr. John F. Coburn
Program Director

TEL: 908-445-6132
FAX: 908-445-6145

*A New Jersey Commission on Science and Technology Center

TABLE OF CONTENTS

# A Producibility Index with Process Capability and Manufacturing Cost


## Abstract

One of the important issues in product design is the assessment of its producibility at a required production rate and an acceptable cost. In this technical report, we review current approaches and then develop and validate a methodology that quantifies the producibility of a product as it relates to its design characteristics. This measure of producibility aims to assure that newly designed products can meet both quality and cost requirements. The measure integrates initial design ideas with actual production concerns and shortens the time required for introducing a new product to the market. It also provides information on the dual use of existing production technologies and facilities for both civilian and military products. This is especially useful for military specified products which are sub-contracted to civilian vendors.


## 1. Introduction:

A product life cycle roughly consists of three phases: product/process design, actual production, and post-production service and support. Traditionally, the early design phase of a product rarely interacts with other downstream phases. However, these downstream phases, such as the actual production and the after-sale customer service, are the phases that actually constitute the major cost of a product during its life cycle. Consequently, a product designed without integrating downstream concerns often requires additional redesigns due to unexpected high manufacturing cost or over-burdened post-production supports. For military products, an nonintegrated design also results in the inflexibility of military logistic mobilization because of the difficulties in converting civilian production facilities to produce military products.

In recognizing the great impact of the design phase on the latter phases and thus on the product life cycle, researchers propose various approaches to integrate the different phases of the life cycle. Feigenbaum (1961) proposed a *Total Quality Control System (TQCS)* where quality control activities are involved in every phase of the product life cycle. Through the common goal of achieving better quality, communications among company divisions are established and the integration of the product life phases becomes essential. Most recently, the *Concurrent Engineering (CE)* (Carter and Baker (1992)) approach specifically integrates different functional divisions and groups that are involved in the product life cycle. The approach has been further enhanced by devising a centralized Data Base Management System (DBMS). This approach

utilizes modern technologies of structural information systems (e.g., Wang (1993)) to establish a highly automatic information collecting and exchanging system. Through this information system, the integration can be achieved more effectively.

As discussed above, the conceptual framework is well established. However, the actual implementation is still in its infant stage. In this technical report, we particularly focus on the implementation methodologies for the integration of both the design phase and the production phase of the product. In the past, product design and production were performed by two separate groups of engineers. In fact, engineers from the two groups received very different disciplines and often had very distinctive, if not conflicting, concerns in the development and production of a product. For example, design engineers tend to focus on the performance and aesthetic aspects of the product while the production/process engineers are most concerned with the easing and streamlining of the product production. When these two groups of engineers do not cooperate in both the design and production activities, we often see either a newly designed product that is impossible or too costly to produce or a production process that is incapable of producing the desired product quality. The purpose of this report is to find a link that allows design engineers to validate their design and production engineers to ease the production set up procedures. We refer to this link between design and production engineers as the *Producibility Index (PI)* which provides a quantified index that takes into account both the quality and cost requirements for producing the products.

Among various types of production systems, the manufacturing/assembly industry appears to be the first to pioneer the implementation of the design-production integration concept. Traditionally, *manufacturing/assembly* is usually referred to as machine tooling type of production processes which fabricates required parts, that are later assembled together to construct the final product. Bolz (1977) provides the design principles that help to improve the designed product's producibility in terms of machining processes. Since the dramatic development of computer technologies in the 80's, production of computer components quickly gained the attentions of manufacturers. Clark (1989) proposes similar design principles for printed circuit boards. These design principles are later derived into a concept called *Design For Manufacturability (DFM)* and *Design For Assembly (DFA)* (see Boothroyd and Dewhurst (1983), Dwivedi and Klein (1986), and Alting and Boothroyd (1994)). However, the DFM and DFA approaches are specifically focused on the physical aspects of manufacturability and assemblability and largely ignore the process/product interaction as related to the product quality.

Unlike the manufacturability and assemblability, *Producibility* provides a quantitative measure that is desirable to evaluate the producibility of the newly designed product by looking at the capability of processes. It should be noted that the processes, that will be used to facilitate the production, should be designed together with the product feature design, as part of the DFM and DFA principles. Now, the question is: what is the process that will be deemed as a *capable* process? While the process capability indices are intensively explored by many researchers (e.g. Kane (1986), Chan, Cheng and Spiring (1988), Bissell (1990) and Boyles (1991)) and are recently summarized in Kotz and Johnson (1993), Harry and Lawson (1992) appear to be the first to pioneer the producibility research by looking at the process capability. Their work is later included in *Producibility Measurement Guidelines* by the Department of the Navy.

In Harry and Lawson's work, the calculation procedures for evaluating the process capability have been very carefully crafted. However, it does not include many concerns that we believe should be addressed in evaluating product producibility. Specifically, there are three issues that we focus on in this report: quality characterizations, production capacity, and rate and product cost. We now explain these issues.

Before evaluating process capability, one should first recognize the quality characteristics of concern. We refer to this step as *quality characterization.* In the conventional calculations of process capability indices, one usually focuses on one particular quality characteristic of interest. In reality, one characteristic is not really enough to reflect the overall process performance since most production processes usually involve more than one important characteristic. Furthermore, there may exist interactions among different characteristics which make the evaluation of process capability difficult for practitioners. As a consequence, some researchers also pay attention to the multivariate process capability indices (e.g., Hubele, Shahriari, and Cheng (1989), and Mendieta, Saleh and Liu (1994)). The proposed multivariate capability indices are, however, doomed to remain theoretical spectacles due to the complexity and the mathematical intangibility. In contrast, we consider multiple characteristics by their effects on the product's functionality instead of their possible interactive relationships. We classify characteristics into three categories: critical, major, and minor. Each one has various influences on the product's functionality. Based on these three characteristics, we develop a more tangible measurement of process capability for multi-characteristic products.

The required production capacity is also an important criterion when evaluating a newly designed product's producibility. A new product development is usually backed by a thorough study of market demand under the principle of concurrent engineering. In the case of military

products, the amount of demand for certain products under certain situations is always the focus of logistic planning. In order for the requirement for the projected production process to be capable of meeting the market demand, the requirement should be considered in the earliest phases of the product life cycle, namely, the product/process design. Taking into account the production capacity of a projected process, one can easily observe that very often the process capability itself is a function of the production rate. In other words, the process capability is not constant over different production rates. In the actual production setting, the production rate is difficult to maintain at a constant level due to usual incidents such as changeovers of feed stock or shifts or even machine breakdown. To more objectively evaluate the overall process capability, different product rates and their corresponding process capabilities should be addressed.

Manufacturing cost is the third issue which we are considering in the producibility index. In the past, improving quality and reducing cost were considered two conflicting tasks. Not until the Japanese competition did American industries realize that the two can actually be achieved together. With the recent advancement of quality technology, some researchers even try to represent product quality in terms of dollars and use the overall cost as an objective function that needs to be minimized. We, however, believe that the product quality is difficult, if not impossible, to assess in terms of cost since poor product quality not only diminishes customers' goodwill impression, which is already difficult to measure, but also causes loss to the entire society ( Taguchi, 1981). Recognizing this, we include in the proposed producibility index (PI) both the process capability index (PCI), which is the measure of process performance on product quality, and the manufacturing cost (MC) which estimates the physical cost for producing a unit of product.

The remainder of this report is organized into four sections. In Section 2, we discuss and review the methodologies used for evaluating process capability. We review four common process capability indices (PCI's): $C_p$, $C_{pk}$, $C_{pm}$, and $C^*_{pm}$, and discuss their uses for different circumstances. Section 3 is devoted to the estimate of the manufacturing cost (MC) where the following are considered: production rate, process efficiency (yield), material cost, labor cost, utility cost, and capital cost. In Section 4, we propose a producibility index (PI) that takes into account both the quality of the product and its cost. The new index is also developed with regard to the quality characterization and the production capacity requirement. Finally, we demonstrate the proposed producibility index using examples from process designs for military combat rations: beef stew and ham slice MRE pouches.

## 2. Process Capability Indices (PCI)

In this section, we review several process capability indices (PCI's) that we will use later in the producibility study. The PCI is chosen instead of the more traditional measure, quality yield, because the modern quality control concept is no longer satisfied by the high quality yield via intensive inspection efforts. "Yield" is simply a measure that indicates the percentage of the products produced that passes the tolerance gauge or meets the specifications. In contrast, PCI is an index that indicates the consistency of the product quality. Figure 1 clearly illustrates this idea.

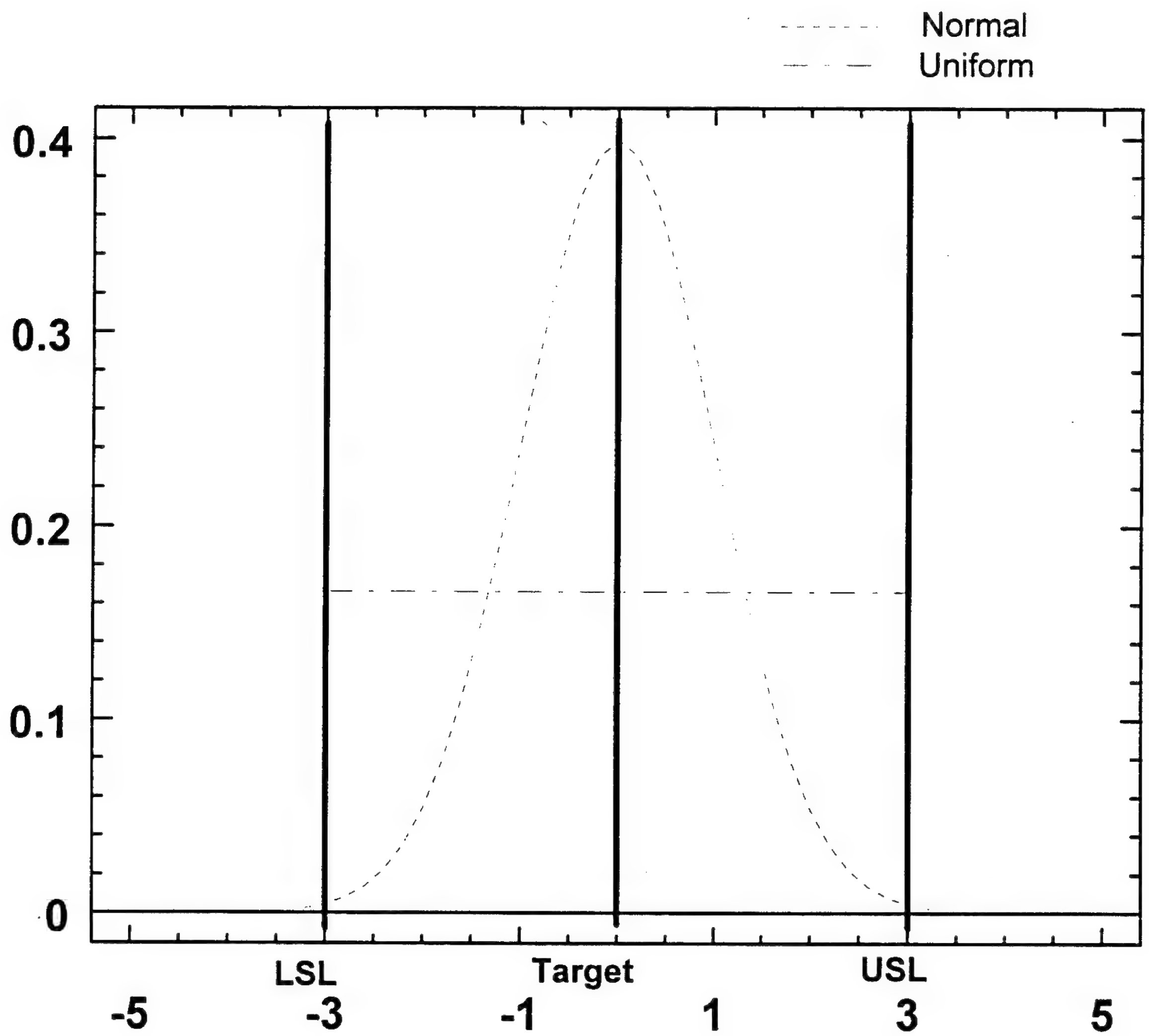



**Figure 1: Comparison between the normal and uniform distributions**

As shown in the Figure 1, the product characteristic being measured has a target value at 0 and lower and upper specification limits (LSL and USL) at -3 and 3, respectively. There are also two probability distributions shown in Figure 1: one is a uniform distribution, *U[-3,3]*, ranging form -3 to 3; and the other is a normal distribution, *N[0, 1]*, with mean 0 and standard deviation 1. It can be clearly observed from Figure 1 that the process with uniform distribution will have 100% yield since all products produced are within the specification limits. On the other hand, the process with normal distribution will only produce 99.73% yield. Nevertheless, the normal distribution clearly produces more consistent product quality since the distribution is more concentrated around the target. Thus, for the purpose of reflecting the quality consistency, yield is certainly not a good measure.

Process Capability Index (PCI) is invented to serve this purpose. It compares the variability of the quality distribution against the specification limits of the product to obtain a fair view of the process performance in producing consistent product qualities. In other words, PCI is more suitable for the modern quality control efforts that focus on reducing the variation of product quality instead of meeting the product specifications.

In this section, we will introduce four PCI measures: $C_p$, $C_{pk}$, $C_{pm}$, and $C_{pm}^*$ that will be used later for the producibility study.

## 2.1 Process Capability Index $C_p$

The process capability measure $C_p$ is the most widely used index. It is expressed as:

$$C_p = \frac{USL - LSL}{6\sigma}$$

To show how this measure effectively reflects the quality consistency, let us calculate the $C_p$ values for the uniform distribution and for the normal distribution as shown in Figure 1. For the uniform distribution *U[-3, 3]*:

$$C_p(U[-3,3]) = \frac{3-(-3)}{6(1.733)} = 0.577 \ ,$$

where the standard deviation for the distribution *U[-3,3]* is 1.733. It can be seen that this $C_p$ value is significantly lower than that for the normal distribution *N(0, 1)*:

$$C_p(N[0,1]) = \frac{3-(-3)}{6(1.0)} = 1.0 \ ,$$

The yield for the uniform distribution is 100% and that for normal distribution is 99.73%. Since we are concerned with the product quality consistency, the $C_p$ measure appears to be much better than the yield. It should be noted that the yield is still considered in our producibility index. However, it is considered a factor in estimating the manufacturing cost rather than being an element of the product quality.

To estimate $C_p$, the standard deviation ($\sigma$) is estimated as:

$$\hat{\sigma} = s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})}{n-1}}$$

where $X_i$'s are the sample observations, $n$ is the sample size of data taken from process, and $\overline{X}$ is the arithmetic average of the observations:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \ .$$

This mean square root estimate of the standard deviation is recommended over the range estimate because the process capability study is usually an off-line study which intends to include all the inevitable variation sources.

$C_p$ measure is good only for a process that can be adjusted to meet the target value. When the mean of the distribution is off the target, the measure is biased regardless of the values of the standard deviation.

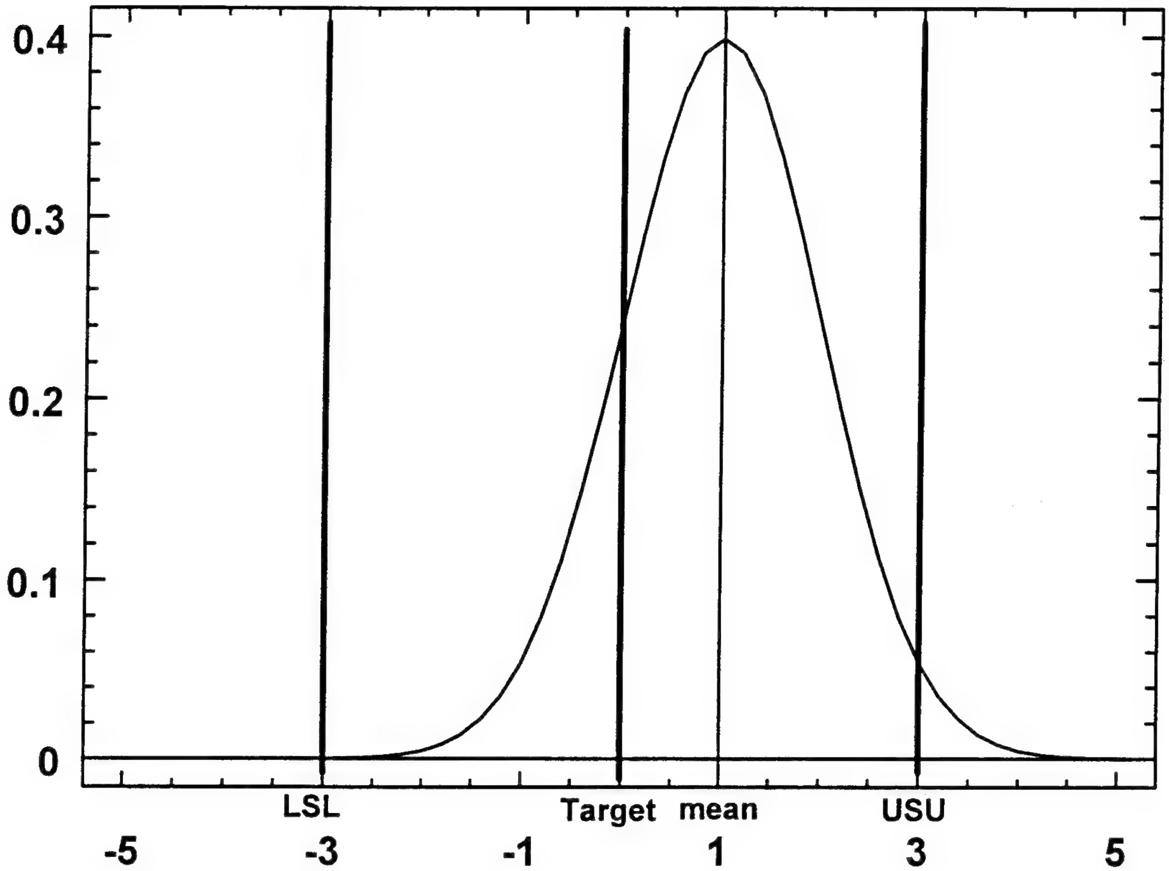



**Figure 2: Process with a shifted mean**

Figure 2 shows a process which has mean at 1 rather than at the target value 0. However, it still has a $C_p$ value of 1.0. There is another concern with $C_p$ measure. From the formula, it is clear that the $C_p$ measure is suitable only for symmetric bilateral specification limits. Next, we should introduce a measure $C_{pk}$ to resolve these problems regarding the $C_p$ measure.

## 2.2 Process Capability Index for Asymmetric Processes $C_{pk}$

$C_{pk}$ has the following form:

$$C_{pk} = \min[CPL,\ CPU] \quad \text{where}$$

$$CPU = \frac{USL - \mu}{3\sigma} \text{ and } CPL = \frac{\mu - LSL}{3\sigma}.$$

To estimate $C_{pk}$, we again use the mean square estimate for the standard deviation and the arithmetic average for the mean:

$$\hat{C}_{pk} = \min[C\hat{P}L,\ C\hat{P}U]\text{, where}$$

$$C\hat{P}U = \frac{USL - \overline{X}}{3s} \text{ and } C\hat{P}L = \frac{\overline{X} - LSL}{3s}\ .$$

When the specification limits are symmetric against the target and the mean of the process coincides with the target and the value of $C_{pk}$ coincides with the value of $C_p$. CPU and CPL can also be used for those characteristics with unilateral tolerance.

Though this measure solves the problems of asymmetric and unilateral specification tolerance it is however still inefficient for processes whose means are off target.

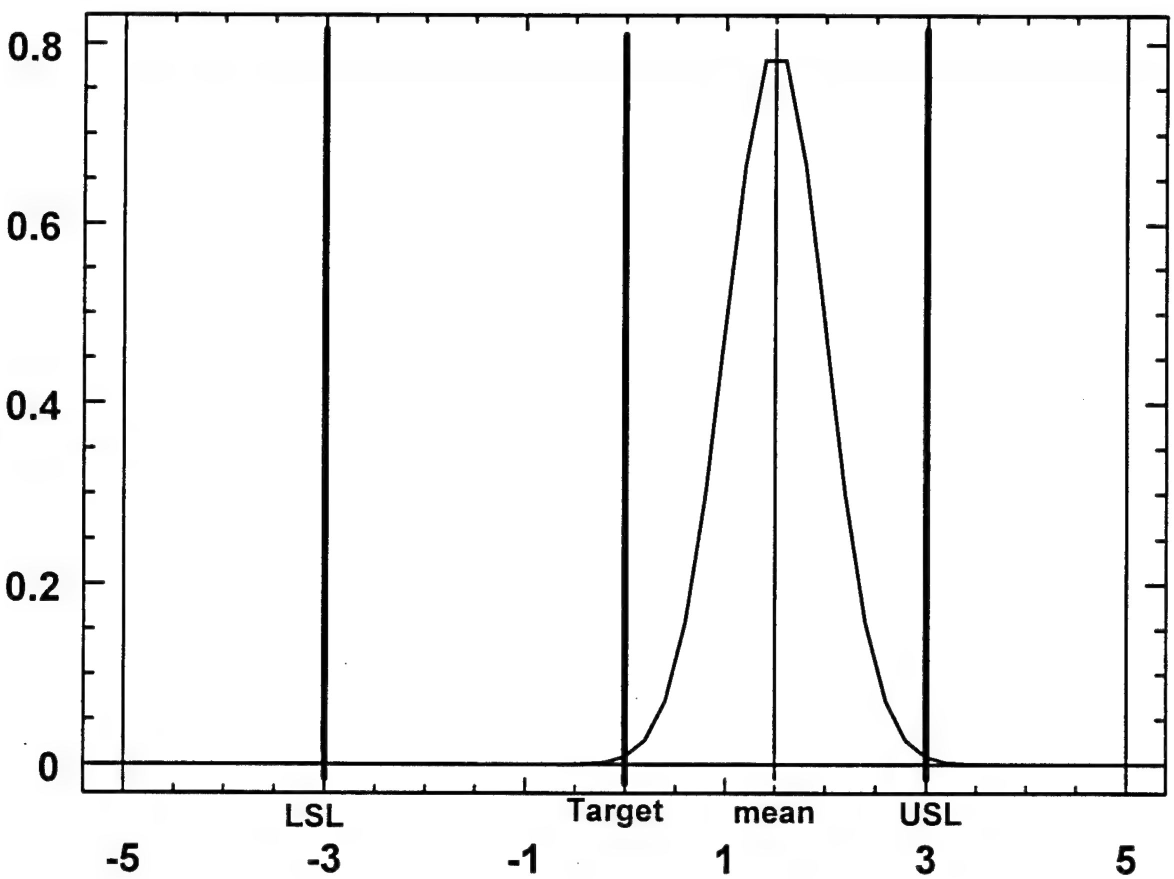



**Figure 3: Process with a high $C_{pk}$ and a shifted mean**

The normal distribution shown in Figure 3 has mean of 1.5, which is well off the target 0, and a standard deviation of 0.5, so the $C_{pk}$ is calculated as:

$$C_{pk} = \min[\frac{1.5-(-3)}{3(0.5)}, \frac{3-1.5}{3(0.5)}] = 1.0$$

To take into account the off-target problem, we introduce $C_{pm}$ measure.

## 2.3 Process Capability Index for Off-target Means $C_{pm}$

$C_{pm}$ has the following form:

$$C_{pm} = \frac{USL - LSL}{6\sigma'} .$$

where

$$\sigma' = \sqrt{E(X-T)^2}$$

is the square root of the mean square error against the target value. Since the mean square error can be further decomposed into two terms, variance and square deviation from target, $\sigma'$ can be rewritten as:

$$\sigma' = \sqrt{\sigma^2 + (\mu - T)^2} .$$

$C_{pm}$ can be therefore written as:

$$C_{pm} = \frac{USL - LSL}{6\sqrt{\sigma^2 + (\mu - T)^2}} = \frac{C_p}{\sqrt{1 + \frac{(\mu - T)^2}{\sigma^2}}} .$$

In other words, when the mean of the process coincides with the target value ($T$), then $C_{pm}$ coincides with $C_p$ . To estimate $C_{pm}$, we need first to estimate $\sigma'$:

$$\hat{\sigma}' = \sqrt{\frac{\sum_{i=1}^{n}(X_i - T)}{n}}\ .$$

$C_{pm}$ is then estimated:

$$\hat{C}_{pm} = \frac{USL - LSL}{6\hat{\sigma}'}\ .$$

Like $C_p$, $C_{pm}$ suffers from problems with asymmetric and unilateral tolerances. This measure is therefore further improved to the $C_{pm}^*$ measure.

## 2.4 Generic Process Capability Index $C_{pm}^*$

$C_{pm}^*$ has the following form:

$$C_{pm}^* = \frac{\min[USL - T, T - LSL]}{3\sigma'}\ .$$

This measure can be used for asymmetric bilateral tolerance. When the characteristic has only unilateral tolerance, the $C_{pm}^*$ is calculated as:

$$C_{pm}^* = \frac{USL - T}{3\sigma'}\ or\ \frac{T - LSL}{3\sigma'}\ .$$

Again, this measure coincides with $C_{pm}$ when the tolerance is symmetric bilateral and additionally with $C_p$ when the mean coincides with the target. The estimate of $C_{pm}^*$ is not different from the $C_{pm}$:

$$\hat{C}_{pm}^* = \frac{\min[USL - T, T - LSL]}{3\hat{\sigma}'}$$

where

$$\hat{\sigma}' = \sqrt{\frac{\sum_{i=1}^{n}(X_i - T)}{n}}\ .$$

Finally, a comparison of the four PCI measures is presented in Appendix C.

## 3. Manufacturing Cost Estimate

To estimate the manufacturing cost, there are several major elements that should be taken into account: *production and schedule efficiency*, *raw materials*, *personnel*, *capital and equipment*, and *utility*. We now explain each element and the relationships among these elements to accurately estimate the final product unit.

- **Production Schedule/Efficiency**

A *minimum production capacity* should be determined based on a prior market study or logistic planning for the case of military supply. This production capacity requirement will lead to the determinations of *production rate* and *production shift schedule*. *Production rate* is the line production rate and *the production shift schedule* determines the operating time of the line to meet the required production capacity. *Process yield* and *efficiency* should then be addressed.

First, the production line should be broken down to element processes. Each process is then evaluated in terms of the process's efficiency. By *efficiency*, we mean the actual average production rate vs. the maximum (or projected) production rate. This is due to the fact that the process is often subject to operating problems such as breakdown and repair. After the process efficiencies are evaluated, it may be necessary to go back to replan production shift schedules in order to meet the minimum production capacity requirement.

Second, for each process, the production yield should be evaluated. By *yield*, we mean the percentage of products that are produced and meet quality requirements. For processes connected in series, the final production yield will be the multiplication of yields from individual processes. The production yield evaluations will be further demonstrated later in Sections 4.4 and 4.5. The results of the yield evaluations will be input into raw material cost estimate. Again, the yield evaluation may need to be fed back to readjust the production shift schedule. For *on-line quality inspection* systems, the *scraping* or *reworking* costs should be taken into account.

- **Raw Materials**

Raw materials include both ingredient materials and packaging materials. When considering the material cost per unit product, the following costs should be taken into account:

1) ingredient material purchase cost;
2) packaging material purchase cost;
3) scraping/reworking costs for yield less than 100%; and
4) material handling cost.

- **Personnel**

The personnel includes:

1) Administration personnel,
2) Operation supervisory,
3) Operation labors, and
4) Quality personnel.

The costs should be estimated for each category based upon the hours required from the planned production shift schedule.

- **Capital/Equipment**

Capital investments are as follows:

1) Production facility: administrative offices, plant floor and warehouse;
2) Production equipment: manufacturing, packaging and quality control equipment;
3) Contingency capital; and
4) Working capital.

The following costs should also be considered:

1) Maintenance/repair,
2) Equipment/facility depreciation,
3) Insurance,
4) Financing, and
5) Taxes.

- **Utility**

By *utility*, we mean the energy supplies required for the production/administration operations. These supplies may vary greatly depending on the type of productions. We list here some energy sources:

1) Natural gas,
2) Burning oil,
3) Process water,
4) Cooling water,
5) Steam,
6) Compressed air, and
7) Electricity.

If applicable, the following costs should be considered,:

1) Taxes,
2) Internal environmental costs: cleaning, facility erosion, and
3) External environmental costs.

We listed the main elements and costs considered under each element. It should be noted that the above listing serves as a guideline for manufacturing cost estimation but is certainly not the only elements that should be considered. Practitioners should develop their own manufacturing cost estimation scheme based on their own situations.

## 4. Producibility Index

We discussed the evaluations of process capability and manufacturing cost in previous sections. In this section, we propose a producibility index that includes these two evaluations as related to the newly designed product. We first present the index, then demonstrate step-by-step procedures that lead to the final calculated result of this index.

The producibility index (PI) proposed has the following form:

$$PI=[PCI_{critical}, PCI_{major}, PCI_{minor}, PCI_{average}, MC].$$

This index is in effect a vector index with 5 elements:

| | |
|---|---|
| $PCI_{critical}$ : | the minimum value of calculated PCI's for critical characteristics; |
| $PCI_{major}$ : | the minimum value of calculated PCI's for major characteristics; |
| $PCI_{minor}$ : | the minimum value of calculated PCI's for minor characteristics; |
| $PCI_{average}$ : | the weighted geometric mean of PCI's for all quality characteristics; and |
| $MC$: | the manufacturing cost estimate. |

Each of the five elements has its own irreplaceable evaluation towards the product's producibility. We will later elaborate on the classifications of the critical, major and minor quality characteristics. But in order to explain these five elements, let us keep in mind that these three types of characteristics represent quality characteristics with three different levels of importance. The process capability index (PCI) used here could be $C_p$, $C_{pk}$, $C_{pm}$, or $C^*_{pm}$ depending on the situation and the needs of study as discussed in Section 2. However, it should be noted that once an adequate index is chosen for a particular quality characteristic, the same index should be used throughout the calculations for the same characteristic. This is very important especially when conducting comparative producibility studies for different product and process designs.

As indicated above, the first three elements are the minimum PCI's from three types of quality characteristics. It is important to know the minimum PCI value for each type of characteristics because an unsatisfactorily low PCI value for even just one quality characteristic will result in the dismissal of the product and process design regardless of the high overall average of the PCI. As explained in Section 2, a value of PCI greater than one is essential for any production setting with statistical process control (SPC) charts. A PCI value less than one

indicates that the window of the control limits is wider than the specification tolerance and therefore violates the control chart's role as a precaution warning device.

The weighted geometric mean of all PCI's is an index of the overall process performance in producing the designed product. Three different types of quality characteristics and different production rates should be weighted differently to reflect the relative importance of the characteristics and the production capacity requirement. The geometric mean is chosen here to calculate the overall average because of its two desirable properties:

1) The geometric mean is more sensitive than the arithmetic mean to small values. This is desirable because a smaller PCI value diminishes producibility considerably.

2) A value of zero will result in a zero geometric mean regardless of how high other values are. This is also desirable since a process with PCI value of zero for any one characteristic is considered absolutely unacceptable regardless of the quality level of other characteristics.

The manufacturing cost (MC) estimate should follow procedures described in Section 3. This cost estimate is an important reference of the product's producibility because it represents the actual manufacturing cost. It should not, however, be treated as the only reference for a product's producibility since there could exist some processes that have a very low manufacturing cost but perform poorly in producing *constant* quality products. It should be noted that the only quality concern of the product and process design included in the manufacturing cost estimate is the production yield. As discussed in Section 3, the production yield is not enough to represent the process performance with regard to product quality. On the other hand, the process capability index alone cannot dictate the producibility because the production could be unnecessarily costly.

We have provided the rationales behind the proposed producibility index. We now describe the step-by-step procedures to carry out the calculation of the producibility index. The calculation steps are as follows:

1) Define Quality Characteristics and Production Capacity Requirement;
2) Identify the type of PCI to be used;
3) Determine the rational subgroup and sampling methodology;
4) Sample data and calculate PCI values;

5) Calculate production yield for manufacturing cost estimate; and
6) Calculate producibility index.

## 4.1 Quality Characterization and Production Capacity Requirement

The first step in evaluating the producibility is to define the characteristics as related to the product's functionality and safety requirements. These characteristics also define a product's individuality. From the principles of DFM and concurrent engineering, the following steps are required for defining a product:

1) Interact with marketing sales and manufacturing engineering to recognize the needs of customers and manufacturing constraints;
2) Specify performance and safety requirements to meet needs from 1;
3) Investigate the feasibility of the specified performance requirements form 2. Go back to 1 if necessary;
4) Generate ideas and solutions regarding the feasible requirements from 3; and
5) Develop a product prototype in cooperation with manufacturing and production engineers.

After going through the above steps, a new product design is now well defined with a set of product characteristics and a minimum requirement for the production capacity. For the purpose of evaluating producibility, the product characteristics should be further identified in terms of the following properties:

- **Importance**

As mentioned earlier, the characteristics defined may have different levels of importance with regard to the product's functionality and safety features. To evaluate the producibility, the characteristics should be weighted differently according to their levels of importance. In our approach, we classify the defined characteristics into the following three categories of importance level:

**Critical:** Those characteristics that could cause damages to human, environment, or any unrecoverable damages when the corresponding specifications are violated.

**Major**: Those characteristics that cause the product malfunctioning, but do not cause damages as critical characteristics do, when the corresponding specifications are violated.

**Minor**: Those characteristics that diminish the product's usability, while they do not cause damages and malfunctioning as critical and major characteristics do, when the corresponding specifications are not met.

Each characteristic defined should be assigned to one of the three categories, which are mutually exclusive. This assignment will later affect the weight of the characteristic in the evaluation of the overall process capability average.

- **Variable/Attribute**

The characteristic is either a *variable* that can be expressed numerically or an *attribute* that can only be described qualitatively, as either defective or non-defective.

- **Stationary Characteristics**

A defined characteristic should also be differentiated by its stationary nature. A *stationary* characteristic is the characteristic that has a process *mean* (for the variable characteristics), or *yield* (for attribute characteristics) that is likely to remain constant throughout the long-term production runs. Characteristics that behave otherwise are called *nonstationary* characteristics.

Such behavior of product characteristic will affect the calculation procedures of PCI's and should be clearly identified before sampling data.

- **Tolerances**

There are different types of specification limits (tolerances) for the characteristics. First, there are *bilateral* tolerances with both upper and lower specification limits. Second, there are *unilateral* tolerances with only an upper or a lower specification limit. For the bilateral tolerance, there is a *symmetric* type of tolerance where the target is at the center between the upper and lower limits and there is an *asymmetric* type of tolerance where the target is not at the center.

This type of the tolerance can be easily observed and identified for *variable* types of characteristics. For the *attribute* type of characteristics, most characteristics are unilateral, that is, they are either defective or non-defective. However, there may exist an attribute characteristic that has two-way possibilities of defects. This case may be considered as a bilateral tolerance.

## 4.2 Type of PCI to be used

Due to the different properties of the characteristics, it is necessary to choose different types of PCI to reflect the true process performance of the characteristics. Different types of PCI's have been discussed in Section 2. Here, we list the type of characteristics and the corresponding PCI to be used.

- variable/stationary/bilateral/symmetric: $C_p$
- variable/stationary/bilateral/asymmetric: $C_{pk}$
- variable/stationary/unilateral: $C_{pk}$
- variable/nonstationary/bilateral/symmetric: $C_{pm}$ (or $C_p$ for long-term production study)
- variable/nonstationary/bilateral/asymmetric: $C_{pm}^*$ (or $C_{pk}$ for long-term production study)
- variable/nonstationary/unilateral: $C_{pm}^*$ (or $C_{pk}$ for long-term production study)
- attribute/stationary/bilateral: $C_p$ (converted from short-term production yield)
- attribute/stationary/unilateral: $C_{pk}$ (converted from short-term production yield)
- attribute/nonstationary/bilateral: $C_p$ (converted from long-term production yield)
- attribute/nonstationary/unilateral: $C_{pk}$ (converted from long-term production yield)

### 4.3 Rational Subgrouping and Sampling Methodology

The objective of the rational subgrouping is to adequately exclude and include the sources of randomness for a specific purpose of variability study. The purpose of this project is to study the process capability as related to a new product design. Therefore, we would like to know how the product quality varies when the product is actually produced. To calculate the process capability indices, we need to estimate the standard deviation as a measure representing the quality variation and then compare it with the specification limits. By doing this (see Section 2), we will be able to evaluate the process performance against the projected product specifications. There are many sources of variation present in the actual production process. Though some are avoidable others are considered unavoidable. For the purpose of the producibility study, we need to subgroup the data sample from the process such that the unavoidable variability sources are included and those avoidable are excluded when estimating the standard deviation. For example, deviations due to raw material quality may be unavoidable and should be included in the study. In other times, the raw material deviations can be well compensated by applying some control measures. In this case, this type of variation source should be excluded. Varying production rate also appears to be an important source of variation and is often unavoidable. For example, if we produce units at high production rate , we may increase variability in the product characteristics and vice versa. Therefore, different sample data may need to be taken to reflect the "true" overall process capability instead of just a process capability for a specific production rate. The effect of varying the production rate is further discussed later in the calculation of the average process capability index.

Rational subgrouping is a very important step in the process capability study. An inadequate subgrouping sample will cause a severe bias in the estimation of the standard deviation and the process capability indices. To prevent biasness of the estimates, design and production engineers together should carefully plan the sampling scheme. Though the scheme often varies for different situations, we provide some generic guidelines as a reference for practitioners.

1. Clearly state the objectives of the data collection.
2. Deliberate as detailed as possible the actual process where data sample to be taken from.
3. List the possible sources of variation.
4. Determine rational subgroups to exclude and include appropriate variation sources.
5. Determine time interval for rational subgroups sampling to avoid dependency between groups.

### 4.4 PCI calculations

In Section 2, we have discussed the formulas for various process capability indices. We now provide procedures for the calculations of the PCI for each type of product characteristics.

• **variable/stationary/bilateral/symmetric:**

This type of characteristic has the most straightforward procedures for the calculation of the PCI. We now demonstrate the step-by-step procedures of estimating PCI. First, we consider the case when the characteristic is variable; that is, it can be expressed numerically. The mean square root estimate of the standard deviation shown in Section 2 can be therefore applied here; that is,

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})}{n-1}}$$

Second, the characteristic is stationary; that is, the mean of the product characteristic remains constant throughout the "in-control" state of the production process. With this constant mean, one can always preset the process such that the mean coincides with the projected target value. This means that we can evaluate the process capability without considering the mean deviations from the target.

Third, the characteristic has a bilateral, symmetric tolerance; that is, the target is in the center of the specification limits. This implies that a simple $C_p$ can be used. To calculate $C_p$, one needs: the specification width (USL-LSL) and the standard deviation as shown in Section 2.1. Hence, the PCI is calculated as:

$$PCI = \frac{USL - LSL}{6\hat{\sigma}} .$$

• **variable/stationary/bilateral/asymmetric:**

This type of characteristics is essentially the same as the preceding type except that the bilateral tolerance is asymmetric. The first two properties ensure that the mean square root estimate of the standard deviation can be used; and concerns about mean deviations from the target can be dismissed. As discussed earlier, when the tolerances are asymmetric the $C_{pk}$ should be used instead of $C_p$ and take the minimum between the two capability indices calculated against the upper specification limit and the lower specification limit is chosen as the $C_{pk}$ value. Since the tolerance is known to be asymmetric, the target value (T) must be known in addition to USL LSL. The PCI can then be calculated as:

$$PCI = \min[\frac{USL - T}{3\hat{\sigma}}, \frac{T - LSL}{3\hat{\sigma}}] ,$$

where $\mu$ (mean) is replaced with T (target value) since the stationary property allows the mean to be set at the target value and remains constant.

- **variable/stationary/unilateral:**

When the target value (T) is known, the PCI should be calculated using $C_{pk}$ as follows:

$$PCI = \frac{USL - T}{3\hat{\sigma}} \text{ or } \frac{T - LSL}{3\hat{\sigma}} ,$$

where the mean is again replaced with T (target value) because of the stationary property.

It should be noted that this type of characteristics also includes the-bigger-the-better and the-smaller-the-better types of characteristics. In these cases, the $C_{pk}$ is calculated as:

$$PCI = \frac{USL - \hat{\mu}}{3\hat{\sigma}} \text{ or } \frac{\hat{\mu} - LSL}{3\hat{\sigma}} ,$$

where the sample mean ($\hat{\mu} = \overline{X} = \sum X_i / n$) should be set, within the process capability, as large or as small as possible for the-bigger-the-better or the-smaller-the-better types of characteristics, respectively.

- **variable/nonstationary/bilateral/symmetric:**

When the characteristic is nonstationary, it implies that the mean of the characteristic of concern is quite sensitive to various sources of variations. This means that we should consider the possible mean deviations from the target when studying the process capability. The appropriate PCI that includes the mean deviations is $C_{pm}$. To calculate the $C_{pm}$, an associated target value should be clearly defined. The PCI is calculated as:

$$PCI = \frac{USL - LSL}{6\sqrt{\frac{\sum_i (X_i - T)^2}{n}}}$$

For most processes, the overall mean for the long-term production run can be still set at the target value despite the nonstationarity of the short-term mean. Therefore, when a target value is not yet determined, the study should be conducted for a long-term production run to include various mean deviations and the $C_p$ can then be used instead of $C_{pm}$. This is because the mean square root estimate of the standard deviation takes into account the possible mean deviations from the target when the long-term mean can be set at the target value.

- **variable/nonstationary/bilateral/asymmetric:**

When the variable characteristic is nonstationary with asymmetric bilateral tolerance, then $C_{pm}$* is the appropriate measure. That is,

$$PCI = \frac{\min[USL - T, T - LSL]}{3\sqrt{\frac{\sum_i (X_i - T)^2}{n}}}.$$

Like the previous type of characteristics where the bilateral tolerance is symmetric, a $C_{pk}$ from a long-term production study can be used and set as the target value.

- **variable/nonstationary/unilateral:**

When the nonstationary variable characteristic is unilateral with a known target value, the $C_{pm}^*$ is used as follows:

$$PCI = \frac{USL - T}{3\sqrt{\frac{\sum_i (X_i - T)^2}{n}}} \quad or \quad \frac{T - LSL}{3\sqrt{\frac{\sum_i (X_i - T)^2}{n}}}$$

Again, when the target value is not yet determined, $C_{pk}$ can be used instead by substituting $T$ with the mean of the process obtained from a long-term production run.

For the-bigger-the-better and the-smaller-the-better type of characteristics, the process should be tested with its highest possible capability for a long-term production run and $C_{pk}$ is calculated as follows:

$$PCI = \frac{USL - \hat{\mu}}{3\hat{\sigma}} \text{ or } \frac{\hat{\mu} - LSL}{3\hat{\sigma}} \quad .$$

• **attribute/stationary/bilateral:**

The attribute characteristics have very different calculation procedures from that of the variable characteristics since they only have qualitative measures instead of numerical measures; that is, the measure is either "conforming" or "nonconforming" to the specification. Moreover, there is no numerical upper or lower specification limits. Thus, the PCI formulas are not applicable for attribute type of characteristics. However, instead of calculating the PCI directly, we can first estimate the percentage yield of conforming products and then convert it to a PCI value by assuming an underlying normal distribution.

To estimate the yield, we usually use a measure called Parts Per Million (ppm) which represents number of nonconforming parts per million of produced parts. This measure is used due to the fact that a capable process usually requires the production of hundreds of thousands or even millions of parts before a nonconforming part is produced. To obtain an estimated ppm, engineers need to run the production and stop only when a projected number of nonconforming parts has been produced.

As mentioned, a capable process may require millions of parts to produce just one defective part. In order to preserve resources, engineers can choose to stop the production when only one nonconforming part is produced. However, if preservation of resource is not of concern, the process should be run until at least 3 nonconforming parts are found in order to obtain a more reliable estimate of ppm especially for nonstationary production processes.

The probability distribution for $r$ nonconforming parts in a total of $N$ parts produced with a probability $p$ of nonconformance is usually assumed to be a Poisson; that is:

$$\Pr(r|N,p) = \frac{(Np)^r e^{-Np}}{r!}$$

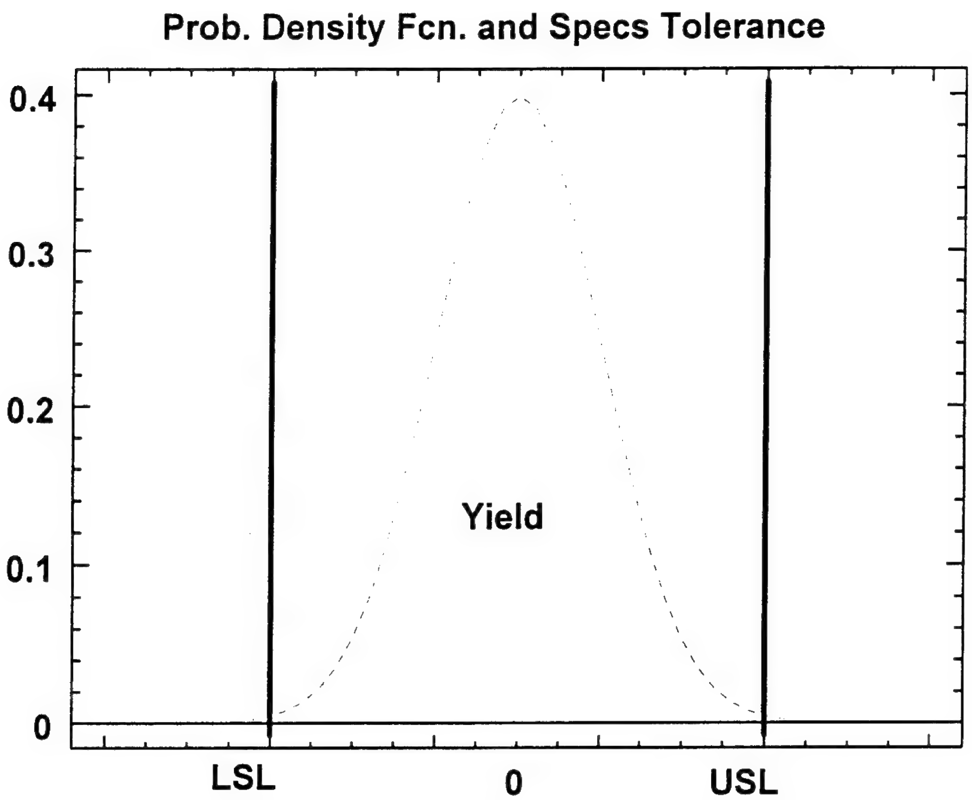
The Poisson distribution is a limiting distribution of a binomial distribution with a vary large number, $N$, of trials (produced parts for our discussion) and a very small probability, $p$, of occurrence (probability of a nonconforming parts in our discussion). Based on the underlying Poisson distribution, we can then estimate the average ppm given a number of $N$ parts produced with $r$ nonconforming parts:

$$p\hat{p}m = \frac{\chi^2_{(0.5,2r)}}{2N} 10^6 \ .$$

where $\chi^2_{(0.5,2r)}$ is the value below which the chi-square distribution with $2r$ degrees of freedom has a probability of 0.5. The above estimate is the "best ppm estimate" in terms of its stability given a small number ($\leq$10) of defective products is found. A table listing the estimated ppm for various values of $N$ and $r$ ($\leq$10) is provided in Appendix A. For $r$ >10, the following simple estimate is satisfactory:

$$p\hat{p}m = \frac{r}{N} 10^6 \ .$$

After the yield (in terms of ppm) is estimated, one can assume an imaginary numerical measure scale with specification limits for this attribute characteristic. Assuming also a normal distribution for the characteristic's imaginary variable, we can now convert the yield to a PCI value. Here, the attribute characteristic has two-way possibility of nonconformance (bilateral). We can thus have the following imaginary normal distribution with mean 0 and standard deviation 1:




where

$$Yield = 1 - \frac{ppm}{10^6} = 1 - 2\Psi(USL)$$

and

$$\Psi(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-x/2} du$$

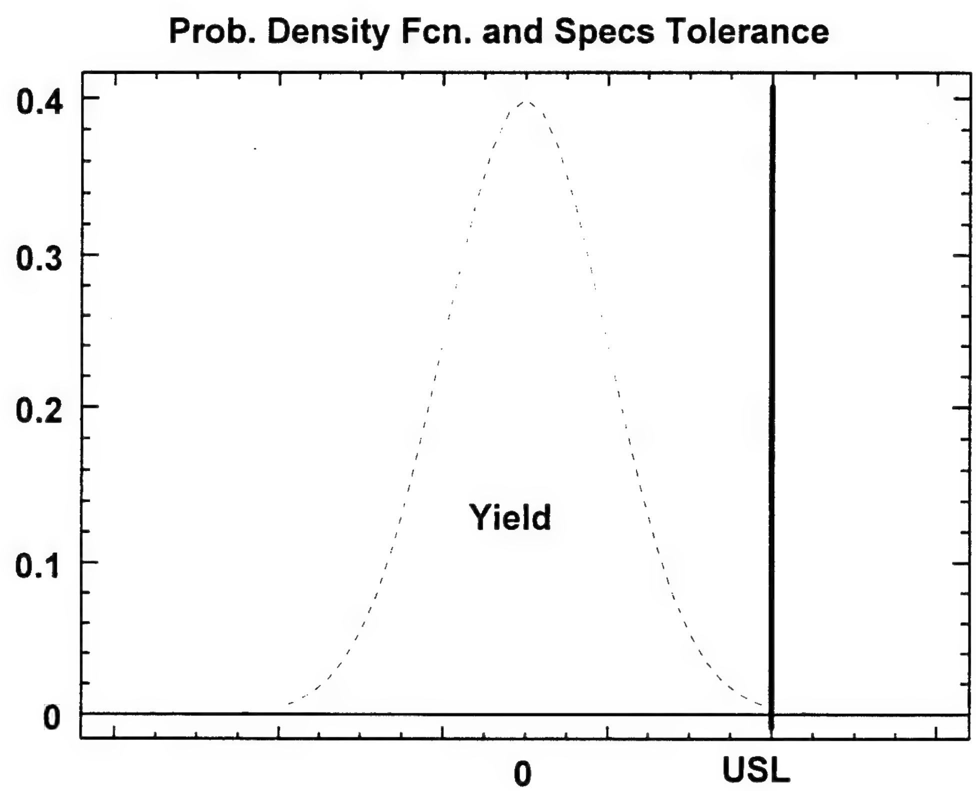
is the probability for having value of $x$ and beyond. From these relationships, the USL can be found from standard table (such as Appendix B) and a PCI is then calculated as:

$$PCI = \frac{USL - 0}{3\sigma} = \frac{USL}{3},$$

where $\sigma$ is 1 for the standard normal distribution.

• **attribute/stationary/unilateral:**

This stationary attribute characteristic has unilateral nonconformance. As in the previous case, we should first run the production to obtain some nonconforming parts. A ppm measure is then estimated based on the underlying Poisson assumption. A numerical normal distribution is then assumed to convert the ppm measure to the corresponding PCI measure. However, in the unilateral case we have only one imaginary specification limit:




where

$$Yield = 1 - \frac{ppm}{10^6} = 1 - \Psi(USL).$$

Again, the USL can be found from the standard table for $\Psi(\cdot)$ (see Appendix B). The PCI is now evaluated:

$$PCI = \frac{USL - 0}{3\sigma} = \frac{USL}{3}.$$

where $\sigma$ is 1 for the standard normal distribution.

The following table provides some basic PCI values and their corresponding process yields. (Other values can be calculated from the above formulas and the table in Appendix B.)

| PCI values | Yield (unilateral spec.) | Yield (bilateral & symmetric spec.) |
|---|---|---|
| 0.9 | 0.996533 | 0.993066 |
| 1.0 | 0.998650 | 0.997300 |
| 1.1 | 0.9995165 | 0.999033 |
| 1.2 | 0.9998408 | 0.9996816 |
| 1.3 | 0.99995178 | 0.99990356 |
| 1.4 | 0.99998656 | 0.99997312 |
| 1.5 | 0.999996549 | 0.999993098 |
| 1.6 | 0.999999181 | 0.999998363 |
| 1.8 | 0.999999963 | 0.999999926 |
| 2.0 | 0.999999998 | 0.999999997 |

• **attribute/nonstationary/bilateral or unilateral:**

For the nonstationary attribute characteristics, the procedures for calculating ppm and PCI are essentially the same as those for the stationary case except that much more units are required to be produced in order to obtain a more reliable estimate of the ppm.

## 4.5 Manufacturing cost estimate:

The manufacturing cost estimate has been discussed in Section 3. In this section, we demonstrate how the production yield can be obtained in order to accurately estimate the manufacturing cost. There are two basic components for estimating the production yield: *quality yield* and *production loss*. *Quality yield* is the percentage of products, that meet all product specifications, produced under normal production condition. *Production loss* is the product percentage that is usually lost during the production run due to the production start-up, change-over or any other causes. The production loss should be estimated based on information from

pilot production runs or from other similar types of productions when the process design is currently not feasible or is not ready for a formal production run.

We first discuss the calculations for the quality yield. For the attribute characteristics, the yield of the process is estimated from the ppm measure as:

$$QualityYield = 1 - \frac{ppm}{10^6}.$$

For the variable characteristics, we need to transform the specification limits to the corresponding limits for the standard normal distribution:

$$LSL' = \frac{LSL - \hat{\mu}}{\hat{\sigma}} \text{ and } \mathrm{USL'} = \frac{\mathrm{USL} - \hat{\mu}}{\hat{\sigma}}.$$

where LSL' and USL' are the limits obtained from the standard normal distribution that correspond the LSL and USL of the quality characteristic respectively. The quality yield is now established:

$$Quality\ Yield = \Psi(LSL') - \Psi(USL')$$

for bilateral tolerance and

$$\begin{aligned} Quality\ Yield &= \Psi(LSL')\ or \\ &\quad 1 - \Psi(USL') \end{aligned}$$

for unilateral tolerance. Appendix B can be again used to find the $\Psi(\cdot)$ values. After estimating the quality yield and the production loss (as defined earlier), we calculate the production yield as:

**Production Yield = (1-Production Loss)×Quality Yield**

### 4.6 Producibility Index Calculation:

As stated at the beginning of this section, the proposed producibility index is expressed as:

$$PI=[PCI_{crit\_min}, PCI_{major}, PCI_{minor}, PCI_{average}, MC]$$

Suppose now that we have a total of $n$ characteristics of the product. Further, assume that among the $n$ characteristics, $n_1$ of them are critical; $n_2$ are major; and $n_3$ are minor. That is,

- critical characteristics: $X_1, X_2, \ldots, X_{n1}$ ;
- major characteristics: $Y_1, Y_2, \ldots, Y_{n2}$ ;
- minor characteristics: $Z_1, Z_2, \ldots, Z_{n3}$ ; *and*
- $n = n_1 + n_2 + n_3$ .

The PCI for each characteristics is calculated by following the procedure described in Section 4.3. We then calculate:

$$PCI_{critical} = \min[PCI_{X_1}, PCI_{X_2}, \ldots, PCI_{X_{n_l}}],$$

$$PCI_{major} = \min[PCI_{Y_1}, PCI_{Y_2}, \ldots, PCI_{Y_{n_2}}] \text{ and}$$

$$PCI_{minor} = \min[PCI_{Z_1}, PCI_{Z_2}, \ldots, PCI_{Z_{n_3}}] \ .$$

To calculate the weighted geometric mean of PCI values for all characteristics, we need to assign weights to each type of characteristics (Derringer (1994)). We use ideal weights $w_1$: $w_2$: $w_3$ to represent the weight ratio for critical, major and minor characteristics, respectively. The weight ratio can be assigned by practitioners based on their needs and situations. We, however, suggest a ratio of *5:3:1*. The weighted geometric mean is calculated as:

$$\begin{aligned} PCI_{average} &= [(PCI_{X_1} .. PCI_{X_{n_1}})^{1/n_1}]^{\frac{w_1}{\sum w_i}} [(PCI_{Y_1} .. PCI_{Y_{n_2}})^{1/n_2}]^{\frac{w_2}{\sum w_i}} [(PCI_{Z_1} .. PCI_{Z_{n_3}})^{1/n_3}]^{\frac{w_3}{\sum w_i}} \\ &= (PCI_{X_1} .. PCI_{X_{n_1}})^{\frac{w_1}{n_1 \sum w_i}} (PCI_{Y_1} .. PCI_{Y_{n_2}})^{\frac{w_2}{n_2 \sum w_i}} [(PCI_{Z_1} .. PCI_{Z_{n_3}})^{\frac{w_3}{n_3 \sum w_i}} \end{aligned}$$

The calculation above is based on the assumption that the individual PCI's do not vary with the production rates. Now, suppose the process performance is sensitive to the production rate for some of the product characteristics. In this case, we need to refine the calculations for the individual PCIs in order to reflect the effect of production rate on the process capability.

Assume that the projected production rate is $PR$ and the tested process mainly has three levels of production rates: low, medium, high or $PR_l$, $PR_m$, $PR_h$. We propose using weighted geometric mean of the PCI for the characteristic which is sensitive to the production rates with a weight ratio of:

$$w_l : w_m : w_h = \frac{PR_l}{PR} : \frac{PR_m}{PR} : \frac{PR_h}{PR}$$

Let $PCI_l$, $PCI_m$, and $PCI_h$ be the PCI values calculated for low, medium and high production rates, respectively. The average PCI for the characteristic is then calculated as:

$$PCI = (PCI_l)^{\frac{w_l}{w_l + w_m + w_h}} (PCI_m)^{\frac{w_m}{w_l + w_m + w_h}} (PCI_h)^{\frac{w_h}{w_l + w_m + w_h}} .$$

This PCI is then used for calculating the overall average PCI as discussed earlier.

To estimate the production rate, we need an overall production yield that takes into account all characteristics of concern:

$$Yield = Yield_{X_1} \bullet .. \bullet Yield_{X_{n_1}} \bullet Yield_{Y_1} \bullet .. \bullet Yield_{Y_{n_2}} \bullet Yield_{Z_1} \bullet .. \bullet Yield_{Z_{n_3}} .$$

We conservatively assume that all characteristics are independent and therefore calculate the final yield of the quality products by multiplying the yields for individual characteristics. After the yield is estimated the manufacturing cost can then be calculated as discussed in Section 3.

We have calculated all the elements of the producibility index (PI) vector. The PI calculated for a specific product/process design is then compared to the PIs of other alternative designs' PIs. The best design based on the PI comparison is then chosen for the actual production.

## 5. Examples of Producibility Indices

In this section, we use the processes designed for producing Meal-Ready-to-Eat (MRE) pouches as examples to demonstrate the proposed producibility index. The quality specifications of MRE pouches have been specified in a series of military standard documents. Here, we are

particularly interested in two products: beef stew and ham slice in MRE pouches (please refer to MIL-B-44059C and MIL-H-44063D, respectively). For the first product, we first test different pouch forming designs where different pouch materials and forming pressures are used. Second, we study effects of different target fill weight designs on the producibility index. For the second product, we compare two different methods of slicing ham into the desired dimensions. We also compare the performance of using a robot or human in placing the ham slices into the open pouches. Comparisons are conducted based on the producibility index proposed above. The calculations of the producibility indices are performed using a spreadsheet program that is specifically designed for the MRE production processes.

## 5.1 Process/Product Designs for the Beef Stew MRE Pouches

The products produced in this study are beef stew pouches. The beef stew is prepared off-line and placed in a filler. Pouches are first formed by applying pressure on the *bottom* film. These formed pouches are then filled with the beef stew using a filler called Raque Filler. Finally, the filled pouches are sealed with a *top* film which is made of the same material as that of the bottom film. The forming, filling and sealing processes handle six pouches simultaneously per cycle. We now study the effects of different designs on the pouch manufacturing cost and the pouch integrity and quality.

In the study, we first focus on the design of the forming process. There are two variables that we try to manipulate: the pouch material and the forming pressure. Both variables dictate the depth, and consequently the volume, of the pouch. For the pouch material, we use two different films produced by Reynolds and Aluswiss. For the forming pressure, we choose two settings for each pouch material. The major concern in this study is the pouch quality that includes critical defects such as unsatisfactory seal width, seal wrinkles, tear/cuts/holes and delamination on the pouch surface. In order to prevent contamination on the edges of opened pouches, and consequently the seal integrity of the finished pouches, due to accidental splashes by the filling process, the speed of the filling process should be adjusted according to the smaller volume of the formed pouch. The larger the pouch volume, the easier, and thus faster, the filling process. On the other hand, the larger pouch volume requires higher forming pressure applied on the bottom film. This higher pressure may result in causing surface defects on the pouch such as delamination and tears. The higher pressure also may cause blowout of the bottom film and thus decreases the efficiency of the entire forming/sealing process due to the stopping of the production line and purging the blown-out pouches before resuming production.

Secondly, we study the effects of different designs on the target fill weights. According to the military standards (MIL-B-44059C), there are minimum requirements for both the net weight and the drained weight of the finished product. When the target fill weights are increased, the process capability against the minimum requirements increases. However, this will result in an increase of the manufacturing cost. It is obvious that there is a tradeoff between the process capability and the manufacturing cost as the target fill weight increases. The producibility index is particularly designed to present the tradeoff and to provide information for decision making on the process/product designs.

We will first analyze the effects of different pouch forming designs on the manufacturing cost given the advantages and disadvantages described above. Following the cost analysis, we study at the process capability index regarding the pouch quality. Through comparisons of both the cost and the process capability, we choose the best design and calculate the producibility index for this design. We then demonstrate the use of the producibility index in the comparison of different target fill weight designs.

### 5.1.1 Manufacturing Cost Analysis for Pouch Forming Designs

The elements of the manufacturing cost analysis have been presented in Section 3. Appendix D presents a complete spreadsheet program that details the elements and the corresponding numbers. In Appendix E, we have a visual representation and formulas of this cost analysis model. We present only the changes in the elements of cost analysis resulting from different designs in the forming process. The settings for each design are shown in the following table.

| Design | Pouch Film | Forming Pressure | Open Pouch Volume |
|---|---|---|---|
| A | Reynolds | 18 psi | 260 cc |
| B | Reynolds | 22 psi | 320 cc |
| C | Aluswiss | 27 psi | 330 cc |
| D | Aluswiss | 24 psi | 305 cc |

Each combination of the film type and the forming pressure results in a different pouch volume. As discussed earlier, the greater the volume, the faster the filling speed. On the other hand, the greater the forming pressure, the less efficient the pouch forming process due to possible blowout of the bottom film. The blowout of the bottom film will also increase the loss

of the film material and thus decrease the actual yield of the pouch material used in the production. In the following table, we present the effects of each design on some basic elements for the manufacturing cost analysis.

| Design | Filling Speed* | Forming Process Efficiency* | Pouch Material Yield* | First Inspection Yield | Final Inspection Yield** |
|---|---|---|---|---|---|
| A | 60 | 90% | 98% | 88.5% | 83% |
| B | 96 | 85% | 95% | 77% | 93.8% |
| C | 102 | 80% | 90% | 92.3% | 100% |
| D | 87 | 90% | 98% | 84.9% | 100% |

In Design A, the minimal formed pouch (260 cc) requires a slow filling speed to avoid seal contamination. Because of the slow speed, the line efficiency and pouch material yield for Design A are relatively high. In Design B, the pouch is formed to the maximum limit (320 cc) for the pouch film from Reynolds. As a result, the line speed can be higher than that in Design A but line efficiency and pouch yield are lower due to occasional blowouts. Design C has the largest formed pouch (330 cc) which enables the line to run in a maximum speed. The line efficiency and pouch yield are, however, the lowest due to a larger number of blowouts. In Design D, the same pouch film (Aluswiss) as in Design C is used but the lesser formed pouch (305 cc) results in better pouch yield and line efficiency but lower line speed.

For all designs, the pouches produced after the forming/sealing process are subject to two 100% visual inspections. The first is performed immediately after the pouch forming/sealing process to sort out defective pouches that fail to meet specifications on the pouch seal and the surface qualities due to poor film qualities or improper sealing process and material handing. The second inspection is performed after the sterilization retort process, the pouches are 100% visually inspected again to sort out defective pouches due to damages on the pouch surface during retort process and handling (loading and unloading) of pouches before and after the retort process. The yields resulting from these two 100% inspections are both listed in the above table and are based on actual observations. Both inspections will greatly affect the final manufacturing

* The numbers are based on expert opinions not actual experimental data.

** The final inspection did not include pouch discoloration a defect. The current manufacturer of the MRE film is still working on resolving this issue.

cost. In Appendix D, we describe in detail all the elements given in Section 3 focusing only on Design C. The following table shows the manufacturing cost calculated using the cost analysis model described in Appendices D and E.

| Design | Manufacturing Cost per Pouch |
|---|---|
| A | \$1.573 |
| B | \$1.370 |
| C | \$1.184 |
| D | \$1.231 |

### 5.1.2 Process Capability Study for the Pouch Defects

The quality of the pouch surface and seal is the only quality characteristic of concern after the pouch forming process. The pouch defects include insufficient seal width ($\leq 1/16$ inch), seal wrinkles, pouch inclusions, delamination, and tears/cuts/holes (please refer to MIL-P-44073B). When any of the above defects is found, the pouch is considered defective and cannot be used. Thus, this characteristic is considered a *critical attribute* quality characteristic and is also *stationary*. Moreover, the quality characteristic is considered *unilateral* since the defects described above are all one-directional. Now, assume that the two 100% visual inspections are 99% effective; that is, among 100 defective pouches, 99 of them will be sorted out through these two inspection procedures. Based on this assumption, we calculate the number of defective pouches per 100 pouches after the two 100% inspections:

$$Defective\ Level(\%) = \left(\frac{1}{Yield_{first} \times Yield_{final}} - 1\right)\left(\frac{1}{Inspection\ Efficiency} - 1\right) \times 100\%$$

where $Yield_{first}$ is the yield from the first 100% inspection; $Yield_{final}$ is the yield from the final 100% inspection; and *Inspection Efficiency* is defined as:

$$Inspection\ Efficiency = \frac{number\ of\ defective\ pouches\ discovered}{total\ number\ of\ defective\ pouches}.$$

An imaginary standard normal distribution with an upper specification limit is then established as discussed earlier:

$$\Psi(USL) = \frac{Defective\ Level\ (\%)}{100}.$$

Since this quality characteristic is considered unilateral, the *PCI* can then be calculated as:

$$PCI = \frac{USL}{3}.$$

The results from the experiments are shown in the following table:

| Design # | $Yield_{first}$ | $Yield_{final}$ | Inspection Efficiency % | Defective Level % | PCI |
|---|---|---|---|---|---|
| A | 0.885 | 0.83 | 99% | 0.365% | 0.8943 |
| B | 0.77 | 0.938 | 99% | 0.388% | 0.8875 |
| C | 0.923 | 1 | 99% | 0.0843% | 1.0469 |
| D | 0.849 | 1 | 99% | 0.1796% | 0.9707 |

It should be mentioned that the defective level is not estimated using the "best ppm estimate" presented earlier because there are more than 10 defective pouches found in each experiment design.

We now compare the PI values for different process/product designs as shown below:

| Design | PI<br>$[PCI_{critical}, PCI_{major}, PCI_{minor}, PCI_{average}, MC]$ |
|---|---|
| A | [0.8943, - , - , 0.8943, 1.573] |
| B | [0.8875, - , - , 0.8875, 1.370] |
| C | [1.0469, - , - , 1.0469, 1.184] |
| D | [0.9707, - , - , 0.9707, 1.231] |

From the above comparison, Design C is an obvious choice given its superior PCI and lower manufacturing cost. It should be noted that there are other quality characteristics that are specified in the military standard but not taken into account in the comparison because they are not affected by the process/product design addressed here.

Examining only the quality characteristic of pouch defects, the process appears incapable even for the best design D. The consumer, military in this case, usually imposes a very strict acceptance sampling plan for the critical quality characteristic. In the military standard (MIL-P44073B), a sample of 200 pouches are taken from a finished product lot. The lot is only accepted when all 200 pouches are found nondefective. Assuming Poisson probability distribution, we can estimate the probability of acceptance ($P_a$) of the lot in terms of the sampling plan and the actual defective level in a lot ($p$):

$$P_a = \sum_{i=0}^{c} \frac{e^{-np}(np)^i}{i!}$$

where $n$ is the sample size and $c$ is the criterion such that when the number of defects exceeds c, the lot is rejected. In the case of pouch defects, $n$ is 200 and $c$ is 0. In Appendix H, we present the Operating Characteristic (OC) curve for this sample plan and a table that shows various actual defective levels and their corresponding expected acceptance probability. From the table, one can find that to have 98% of the finished product lots to be accepted, the actual defective level should be less than 0.0001, that is, a yield of 0.9999. If we translate the yield to a PCI value, the PCI value should be no less than 1.24 in order to have 98% of your finished products accepted.

In our process design (C), the yield is merely 0.9157 (PCI=1.0469). This means that the acceptance rate (form Appendix H) will be only about 85%. This is certainly not satisfactory and the process should be further improved.

In the next section, we study the tradeoff between the manufacturing cost and the process capability for different designs of the target fill weights.

### 5.1.3 Producibility Indices for Different Designs of the Target Fill Weights

In the previous section, we have chosen the best pouch forming design, namely, a Aluswiss film with a pouch forming pressure of 27 psi. In this section, we examine other design aspects of the beef stew pouch. Particularly, we focus on the raw material target fill weights. In the military standard for the beef stew pouch, we have minimum weight requirements for the net weight and beef and vegetables drained weights. In addition, there are specifications for the fat content, the salt content and the connective tissue in the beef. Besides the finished product specifications, we might also have *in process* specifications or specifications that have to be adhered to due to the design of the process. As an example of such internal specifications, we

will discuss the maximum net weight requirement. The maximum net weight* (e.g. 250g) is one of the critical factors on which the thermal process design is based to ensure thorough sterilization of the food pouches. Though this requirement is not listed as one of finished product specifications, it is certainly an important in-process specification that the product/process should be designed to conform to. We summarize the specifications as follows (please refer to MIL-B-44059C):

| | | |
|---|---|---|
| Net Weight: | Individual pouch | $\geq 212.6$ g |
| | Average of 20 | $\geq 226.7$ g |
| | Individual pouch | $\leq 250$ g (in-process specification) |
| Beef Drained Weight: | Individual pouch | $\geq 56.7$ g |
| | Average of 20 | $\geq 68.0$ g |
| Vegetable Drained Weight: | Individual pouch | $\geq 34.0$ g |
| | Average of 20 | $\geq 45.3$ g |
| Salt Content: | $0.5\% \leq$ Individual $\leq 1.3\%$ | |
| Connective Tissue: | $\leq 10.0$ g | |

Among the listed quality characteristics, the maximum net weight is the only one that is considered *critical* since any pouch exceeding the maximum weight could cause a failure of the thermal sterilization process and thus threatens the users' health. The remaining quality characteristics specifications, including the minimum net weight requirement for the net weight, are listed as *major* except the connective tissue, which is only considered *minor*. It is interesting to observe that the above specifications are somehow different from specifications we discussed in this report. For the weights and the fat content requirements, there are not only specifications for individual pouch but also specification for the average of a sample of 20 pouches. To calculate the PCI value, we take the minimum value of the PCI values for the individual and the average specifications. For example, the PCI value for the net weight minimum requirement is calculated as:

* For simplicity, we assume that the beef fill weight and the vegetable fill weight are not critical factors of the thermal process and are not bound by the in-process specifications.

$$PCI_{min\_net} = \min[\frac{T_{net} - 212.6}{3\hat{\sigma}_{net}}, \frac{T_{net} - 226.7}{3\hat{\sigma}_{net} / \sqrt{20}}]$$

where $T_{net}$ is the target fill weight of beef stew and $\hat{\sigma}_{net}$ is the estimated standard deviation of the individual pouch net weight. Similarly, we calculate the PCI values in the same fashion for other quality characteristics when both individual and average requirements are present.

It can also be observed that for the minimum weights requirements one can indefinitely increase the PCI values by increasing the target fill weights. However, the manufacturing cost will also be increased because of the extra amount of raw materials required. For the net weight specifications, increasing the PCI value for the minimum net weight requirement also diminishes the PCI value for the maximum net weight requirement. Our proposed producibility index will clearly demonstrate these tradeoffs. Before we calculate the producibility index, we first find out the relationships among the ingredients of the beef stew and the effects of the ingredient fill weights on the contents of *connective tissue*, *fat*, and *salt*. The beef stew is made of three ingredients: *gravy, beef, and vegetables*. There are three target fill weights that can be chosen by the manufacturer: *target pouch fill weight, target beef fill weight, and target vegetable fill weight*. Once these three fill weights are chosen, the following product characteristics are then calculated as:

Gravy fill weight = target pouch fill weight – target beef fill weight – target vegetable fill weight

Target beef drained weight = beef retort yield × target beef fill weight
= 85%* target beef fill weight

Target vegetable drained weight = vegetable retort yield × target vegetable fill weight
= 135%* target vegetable fill weight
(dehydro frozen potato used)

Target salt content
= 100%×(1.23%* target gravy fill weight + 2.36%* target beef fill weight) / target pouch fill weight

* The numbers are based on estimates from experts.

Target weight of connective tissue = 6.5%* target beef drained weight

We conduct experiments to estimate the standard deviation for each quality characteristic. The results are shown in the following table:

| Quality Characteristic | Estimated Standard Deviation |
|---|---|
| Net Weight (g) | 4.57 |
| Beef Drained Weight (g) | 4.448 |
| Vegetables Drained Weight (g) | 8.33 |
| Salt Content (%) | 0.107 |
| Connective Tissue (g) | 0.507 |

It is found that the estimated standard deviations are not sensitive to the mean in the range of interest in our study. That is, changes in the target fill weights will not affect the estimated standard deviations for the listed quality characteristics. This is important since it would require additional experiments to estimate the standard deviations that are changed due to different fill weights. We now study the following two sets of the target fill weights:

| Design # | Pouch Fill Weight | Beef fill Weight | Vegetable fill Wt. |
|---|---|---|---|
| A | 232g | 85g | 51g |
| B | 231g | 87g | 49g |

We then calculate the PCI values in the following table:

| Design # | Critical | Major | | | | Minor | Unit Cost |
|---|---|---|---|---|---|---|---|
| | Max Net Weight | Min. Net Weight | Beef Drain Wt. | Veget. Drain Wt. | Salt Content | Connect. Tissue | |
| A | 1.313 | 1.415 | 1.155 | 1.395 | 1.194 | 3.485 | 1.192 |
| B | 1.386 | 1.342 | 1.281 | 1.286 | 1.120 | 3.412 | 1.199 |

* The numbers are based on estimates from experts.

Here, we take the maximum and minimum net weight requirements of design A as examples to demonstrate the calculations of PCI values:

$$PCI_{\max\_net} = \frac{USL - T}{3\hat{\sigma}} = \frac{250 - 232}{3 \times 4.57} = 1.313 \quad \text{and}$$

$$PCI_{\min\_net} = \min\left[\frac{232 - 212.6}{3 \times 4.57}, \frac{232 - 226.7}{3 \times 4.57 / \sqrt{20}}\right] = 1.415 \ .$$

Finally, we calculate the producibility index. Again, we take the design A as an example:

$PCI_{critical} = \min[1.313] = 1.313$;

$PCI_{major} = \min[1.415,\ 1.155,\ 1.395,\ 1.194] = 1.155$;

$PCI_{minor} = \min[3.485] = 3.485$ and

$$PCI_{average} = [1.313^5 \times (1.415 \times 1.155 \times 1.395 \times 1.194)^{3/4} \times 3.485^1]^{\frac{1}{5+3+1}} = 1.453.$$

We use the importance ratio 5:3:1 for the calculation of average PCI. The following table shows the comparison of PI's between designs A and B:

| Design | PI<br>$[PCI_{critical}, PCI_{major}, PCI_{minor}, PCI_{average}, MC]$ |
|---|---|
| A | [1.313, 1.155 , 3.485, 1.453, 1.192] |
| B | [1.386, 1.120 , 3.412 , 1.482, 1.199] |

It is interesting to observe that the second design (B) is an obvious attempt to correct the first design (A). In the first design, the PCI for the critical characteristic, maximum net weight, is not satisfactory. We thus decrease the pouch fill weight by 1 gram. Also, the PCI value for the beef drained weight is the minimum (1.155) among the major quality characteristics and is considered unacceptable. In the second design, we increase the beef fill weight and raise the PCI value for the beef drained weight to 1.28. In this design, the salt content becomes the major characteristic with the minimum PCI (1.12). This is, however, easily correctable by decreasing the salt content in the gravy. The manufacturing cost is also higher, by 0.7 cents, in the second

design due to the significant increase in the beef fill weight, the most expensive raw material. The PCI value for the connective tissue in this case is very high and does not concern us at all for the fill weights design. Now, it is up to the manufacturer to choose the better design. If both designs A and B are not acceptable, further developments of new designs may be necessary. Appendix F shows the spreadsheet program for the design B.

### 5.2 Producibility Index for the Ham Slice Pouches

In this section, we study different designs for the production of ham slice pouches. There are basically four different design settings:

A: Hand Fill, Automatic Slicing,
B: Hand Fill, Automatic Slicing/Sizing,
C: Robot Fill, Automatic Slicing, and
D: Robot Fill, Automatic Slicing/Sizing.

There are two filling designs: hand fill and robot fill. Two filling labors are required to place ham slices into the open pouches in order to meet the line speed: 60 pouches/minute. When robot is used to place the ham slices, it requires no labors. For both hand fill and robot fill, two labors are required to unpack the ham boxes and place the ham loafs on the slicer. These two labors are also responsible for sorting out broken slices or slices with unsatisfactory air pockets.

There are also two different designs in the ham slicing process. In the first design, the automatic slicing device cuts off ham slices from the ham loaf. In the second design, the slicer is also equipped with sizing device that cuts off the surface of the ham loaf to obtain more consistent shapes and weights of ham slices. The second design, however, increases the raw material cost by 10 cents per pound filled. The following table summarizes the differences in the elements of cost analysis resulting from the four designs:

| Design | First Inspection Yield (%) | Ham Cost ($/lb.) | Target Fill Weight (g) | No of Filling Labor | Capital Robot ($) | Utility Cost Robot |
|---|---|---|---|---|---|---|
| A | 96.3% | 1.60 | 155 | 2 | 0.00 | 0.00 |
| B | 96.3% | 1.70 | 145 | 2 | 0.00 | 0.00 |
| C | 94.4% | 1.60 | 155 | 0 | 150,000 | air: 5 $ft^3$/hr<br>elect: 5 kW |
| D | 94.4% | 1.70 | 145 | 0 | 150,000 | air: 5 $ft^3$/hr<br>elect: 5 kW |

Like beef stew pouches, the ham slice pouches have to go through two 100% inspections: one before and the other after the retort process. The robot appears to produce more defect pouches. This is possibly caused by the inaccuracy of the robot arm. The target fill weight for the slicing device is higher than the slicing/sizing device because the variations of resulted net weight and drained weight are higher without sizing. Again, we assume 99% efficiency of two 100% inspections on the pouch defects and calculate the defective level (%) of finished pouches using the following formula:

$$Defective\ Level\,(\%) = \left(\frac{1}{Yield_{first} \times Yield_{final}} - 1\right)\left(\frac{1}{Inspection\ Efficiency} - 1\right) \times 100\%$$

where $Yield_{first}$ is the yield from the first 100% inspection; $Yield_{final}$ is the yield from the final 100% inspection. An imaginary standard normal distribution with an upper specification limit is then established as discussed earlier:

$$\Psi(USL) = \frac{Defective\ Level\ (\%)}{100}.$$

Again, this quality characteristic is considered unilateral and the *PCI* can then be calculated as:

$$PCI = \frac{USL}{3}.$$

The results from the experiments are shown in the following table:

| Design | $Yield_{first}$ | $Yield_{final}$ | Inspection Efficiency % | Defective Level % | PCI |
|---|---|---|---|---|---|
| A & B | 0.963 | 0.99 | 99% | 0.0494% | 1.098 |
| C & D | 0.944 | 0.99 | 99% | 0.0707% | 1.064 |

As in the case of beef stew pouches, there are also specifications on the net weight and the drained weight (please refer to MIL-H-44063D):

| | | |
|---|---|---|
| Net Weight: | Individual pouch | $\geq$ 113.4 g |
| | Average of 20 | $\geq$ 127.6 g |
| | Individual pouch | $\leq$ 180 g (in-process specification) |
| Beef Drained Weight: | Individual pouch | $\geq$ 102.1 g |
| | Average of 20 | $\geq$ 107.7 g |

We again conduct experiments to gather data for estimating the standard deviations. The results are shown in the following table:

| Design | Net Weight S.D. | Drained Wt. S.D. |
|---|---|---|
| A & C | 7.795 | 7.692 |
| B & D | 3.199 | 5.851 |

Based on the above specifications and estimated standard deviations, we then calculate the PCI values. We summarize the results in the following table:

| Design # | Critical | | Major | | Unit Cost |
|---|---|---|---|---|---|
| | Max Net Wt. | Pouch Defect | Drain Wt. | Min Net Wt. | |
| A | 1.069 | 1.098 | 1.042 | 1.779 | 1.389 |
| B | 3.126 | 1.098 | 1.128 | 1.565 | 1.422 |
| C | 1.069 | 1.064 | 1.042 | 1.779 | 1.424 |
| D | 3.126 | 1.064 | 1.128 | 1.565 | 1.443 |

The producibility indices are then calculated:

| Design # | PI<br>[$PCI_{critical}$, $PCI_{major}$, $PCI_{minor}$, $PCI_{average}$, $MC$] |
|---|---|
| A | [1.069, 1.042 , - , 1.180, 1.389] |
| B | [1.098, 1.128 , - , 1.635, 1.422] |
| C | [1.069, 1.042 , - , 1.169, 1.424] |
| D | [1.064, 1.128 , - , 1.619, 1.443] |

From the above comparisons, Design B, hand fill with slicing/sizing, appears to be the best design though the manufacturing cost is 3.3 cents higher than Design A. Appendix G shows the spreadsheet program for Design B.

## 6.0 Summary

We have developed a process producibility index which assesses the producibility of a product with given specifications. The index will determine whether the specifications of the product are producible (with acceptable cost) or not. We then demonstrated the application of this index to two MRE products, namely; beef stew pouches and sliced ham pouches.

## Reference


Alting, L. and G. Boothroyd, *Manufacturing Engineering Processes*, New York, Marcel Dekker, 1994.

Bissell, A. F., "How Reliable is Your Capability Index?", *Appl. Statist.*, 39, pp. 331-340, 1990.

Boothroyd, G. and P. Dewhurst, *Design for Assembly*, Amherst, Mass., University of Massachusetts, Dept. of Mechanical Engineering, 1983.

Boyles, R. A., "The Taguchi Capability Index", *Journal of Quality Technology*, 23, pp. 17-26, 1991.

Carter, D. E. and B. S. Baker, *Concurrent Engineering*, Reading, Mass., Addison-Wesley, 1992.

Chan, L. K., S. W. Cheng and F. A. Spring, " A New Measure of Process Capability: $C_{pm}$". *Journal of Quality Technology*, 20, pp 162-175, 1988.

Department of the Navy, *Producibility Measurement Guidelines*, 1991.

Derringer, G.C. , "A Balancing Act: Optimizing a Product's Properties," *Quality Progress,* pp 51-58, June 1994.

Dwivedi, S. N. and B. R. Klein, "Design for Manufacturability Makes Dollars and Sense", *CIM Review,* pp 53-59, Spring 1986.

Feigenbaum, A. V., *Total Quality Control*, McGraw-Hill, New York, 1961.

Harry, M. J. and J. R. Lawson, *Six Sigma Producibility Analysis and Process Characterization*, Addison-Wesley Publishing Company, Reading, Massachusetts, 1992.

Hebele, N. F., H. Shahriari and C. S. Cheng, "A Bivariate Process Capability Vector", *Statistics and Design in Process Control: Keeping Pace with Automated Manufacturing*, Edited by J. B. Keats and D. C. Montgomery, Marcel Dekker, New York, 1989.

Kane, V. E. , "Process Capability Indices", *Journal of Quality Technology*, 18, pp 41-52, 1986.

Kotz, S. and N. L. Johnson, *Process Capability Indices*, Chapman and Hall, London, 1993.

Mendieta, G.R., D. T. Saleh, and M. C. Liu, “Survey of Multivariate Process Capability,” *Proceedings of the Second International Conference on Applied Statistics in Industry,* Wichita, Kansas, June, 1994.

MIL-B-44059C, "Military Specification: Beef Stew, Thermostabilized, for Meal, Read-to-Eat", DoD, 1986.

MIL-H-44063D, "Military Specification: Ham Slice, Smoke Flavoring Added, Thermostabilized, for Meal, Read-to-Eat", DoD, 1987.

MIL-P-44073B, "Military Specification: Packaging and Thermoprocessing of Foods in Flexible Pouches", DoD, 1983.

Taguchi, G. and Y.-I. Wu, *Introduction to Off-line Quality Control*, Central Japan Quality Control Association, Japan, 1979.

Wang, R. Y., editor, *Information Technology In Action*, Prentice Hall, Englewood Cliff, New Jersey, 1993.

# APPENDIX A

## Estimate of ppm from N and r

| N \ r → | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 70233 | 168484 | 267886 | 367584 | 467402 | 567280 | 667193 | 767127 | 867076 | 967036 |
| 20 | 35117 | 84242 | 133943 | 183792 | 233701 | 283640 | 333596 | 383564 | 433538 | 483518 |
| 30 | 23411 | 56161 | 89295 | 122528 | 155801 | 189093 | 222398 | 255709 | 289025 | 322345 |
| 40 | 17558 | 42121 | 66971 | 91896 | 116850 | 141820 | 166798 | 191782 | 216769 | 241759 |
| 50 | 14047 | 33697 | 53577 | 73517 | 93480 | 113456 | 133439 | 153425 | 173415 | 193407 |
| 60 | 11706 | 28081 | 44648 | 61264 | 77900 | 94547 | 111199 | 127855 | 144513 | 161173 |
| 70 | 10033 | 24069 | 38269 | 52512 | 66772 | 81040 | 95313 | 109590 | 123868 | 138148 |
| 80 | 8779 | 21061 | 33486 | 45948 | 58425 | 70910 | 83399 | 95891 | 108385 | 120879 |
| 90 | 7804 | 18720 | 29765 | 40843 | 51934 | 63031 | 74133 | 85236 | 96342 | 107448 |
| 100 | 7023 | 16848 | 26789 | 36758 | 46740 | 56728 | 66719 | 76713 | 86708 | 96704 |
| 150 | 4682 | 11232 | 17859 | 24506 | 31160 | 37819 | 44480 | 51142 | 57805 | 64469 |
| 200 | 3512 | 8424 | 13394 | 18379 | 23370 | 28364 | 33360 | 38356 | 43354 | 48352 |
| 250 | 2809 | 6739 | 10715 | 14703 | 18696 | 22691 | 26688 | 30685 | 34683 | 38681 |
| 300 | 2341 | 5616 | 8930 | 12253 | 15580 | 18909 | 22240 | 25571 | 28903 | 32235 |
| 350 | 2007 | 4814 | 7654 | 10502 | 13354 | 16208 | 19063 | 21918 | 24774 | 27630 |
| 400 | 1756 | 4212 | 6697 | 9190 | 11685 | 14182 | 16680 | 19178 | 21677 | 24176 |
| 450 | 1561 | 3744 | 5953 | 8169 | 10387 | 12606 | 14827 | 17047 | 19268 | 21490 |
| 500 | 1405 | 3370 | 5358 | 7352 | 9348 | 11346 | 13344 | 15343 | 17342 | 19341 |
| 600 | 1171 | 2808 | 4465 | 6126 | 7790 | 9455 | 11120 | 12785 | 14451 | 16117 |
| 700 | 1003 | 2407 | 3827 | 5251 | 6677 | 8104 | 9531 | 10959 | 12387 | 13815 |
| 800 | 878 | 2106 | 3349 | 4595 | 5843 | 7091 | 8340 | 9589 | 10838 | 12088 |
| 900 | 780 | 1872 | 2977 | 4084 | 5193 | 6303 | 7413 | 8524 | 9634 | 10745 |
| 1.000 | 702 | 1685 | 2679 | 3676 | 4674 | 5673 | 6672 | 7671 | 8671 | 9670 |
| 1.100 | 638 | 1532 | 2435 | 3342 | 4249 | 5157 | 6065 | 6974 | 7883 | 8791 |
| 1.200 | 585 | 1404 | 2232 | 3063 | 3895 | 4727 | 5560 | 6393 | 7226 | 8059 |
| 1.300 | 540 | 1296 | 2061 | 2828 | 3595 | 4364 | 5132 | 5901 | 6670 | 7439 |
| 1.400 | 502 | 1203 | 1913 | 2626 | 3339 | 4052 | 4766 | 5479 | 6193 | 6907 |
| 1.500 | 468 | 1123 | 1786 | 2451 | 3116 | 3782 | 4448 | 5114 | 5781 | 6447 |
| 1.600 | 439 | 1053 | 1674 | 2297 | 2921 | 3546 | 4170 | 4795 | 5419 | 6044 |
| 1.700 | 413 | 991 | 1576 | 2162 | 2749 | 3337 | 3925 | 4513 | 5100 | 5688 |
| 1.800 | 390 | 936 | 1488 | 2042 | 2597 | 3152 | 3707 | 4262 | 4817 | 5372 |
| 1.900 | 370 | 887 | 1410 | 1935 | 2460 | 2986 | 3512 | 4038 | 4564 | 5090 |
| 2.000 | 351 | 842 | 1339 | 1838 | 2337 | 2836 | 3336 | 3836 | 4335 | 4835 |
| 2.200 | 319 | 766 | 1218 | 1671 | 2125 | 2579 | 3033 | 3487 | 3941 | 4396 |
| 2.400 | 293 | 702 | 1116 | 1532 | 1948 | 2364 | 2780 | 3196 | 3613 | 4029 |
| 2.600 | 270 | 648 | 1030 | 1414 | 1798 | 2182 | 2566 | 2950 | 3335 | 3719 |
| 2.800 | 251 | 602 | 957 | 1313 | 1669 | 2026 | 2383 | 2740 | 3097 | 3454 |
| 3.000 | 234 | 562 | 893 | 1225 | 1558 | 1891 | 2224 | 2557 | 2890 | 3223 |
| 3.200 | 219 | 527 | 837 | 1149 | 1461 | 1773 | 2085 | 2397 | 2710 | 3022 |
| 3.400 | 207 | 496 | 788 | 1081 | 1375 | 1668 | 1962 | 2256 | 2550 | 2844 |
| 3.600 | 195 | 468 | 744 | 1021 | 1298 | 1576 | 1853 | 2131 | 2409 | 2686 |
| 3.800 | 185 | 443 | 705 | 967 | 1230 | 1493 | 1756 | 2019 | 2282 | 2545 |
| 4.000 | 176 | 421 | 670 | 919 | 1169 | 1418 | 1668 | 1918 | 2168 | 2418 |
| 4.200 | 167 | 401 | 638 | 875 | 1113 | 1351 | 1589 | 1826 | 2064 | 2302 |
| 4.400 | 160 | 383 | 609 | 835 | 1062 | 1289 | 1516 | 1743 | 1971 | 2198 |
| 4.600 | 153 | 366 | 582 | 799 | 1016 | 1233 | 1450 | 1668 | 1885 | 2102 |
| 4.800 | 146 | 351 | 558 | 766 | 974 | 1182 | 1390 | 1598 | 1806 | 2015 |
| 5.000 | 140 | 337 | 536 | 735 | 935 | 1135 | 1334 | 1534 | 1734 | 1934 |
| 5.500 | 128 | 306 | 487 | 668 | 850 | 1031 | 1213 | 1395 | 1577 | 1758 |
| 6.000 | 117 | 281 | 446 | 613 | 779 | 945 | 1112 | 1279 | 1445 | 1612 |

N = a unit of product, an opportunity for nonconformities, etc.
r = the number of nonconformities.

| N \ r → | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 6.500 | 108 | 259 | 412 | 566 | 719 | 873 | 1026 | 1180 | 1334 | 1488 |
| 7.000 | 100 | 241 | 383 | 525 | 668 | 810 | 953 | 1096 | 1239 | 1381 |
| 7.500 | 94 | 225 | 357 | 490 | 623 | 756 | 890 | 1023 | 1156 | 1289 |
| 8.000 | 88 | 211 | 335 | 459 | 584 | 709 | 834 | 959 | 1084 | 1209 |
| 8.500 | 83 | 198 | 315 | 432 | 550 | 667 | 785 | 903 | 1020 | 1138 |
| 9.000 | 78 | 187 | 298 | 408 | 519 | 630 | 741 | 852 | 963 | 1074 |
| 9.500 | 74 | 177 | 282 | 387 | 492 | 597 | 702 | 808 | 913 | 1018 |
| 10.000 | 70 | 168 | 268 | 368 | 467 | 567 | 667 | 767 | 867 | 967 |
| 11.000 | 64 | 153 | 244 | 334 | 425 | 516 | 607 | 697 | 788 | 879 |
| 12.000 | 59 | 140 | 223 | 306 | 390 | 473 | 556 | 639 | 723 | 806 |
| 13.000 | 54 | 130 | 206 | 283 | 360 | 436 | 513 | 590 | 667 | 744 |
| 14.000 | 50 | 120 | 191 | 263 | 334 | 405 | 477 | 548 | 619 | 691 |
| 15.000 | 47 | 112 | 179 | 245 | 312 | 378 | 445 | 511 | 578 | 645 |
| 16.000 | 44 | 105 | 167 | 230 | 292 | 355 | 417 | 479 | 542 | 604 |
| 17.000 | 41 | 99 | 158 | 216 | 275 | 334 | 392 | 451 | 510 | 569 |
| 18.000 | 39 | 94 | 149 | 204 | 260 | 315 | 371 | 426 | 482 | 537 |
| 19.000 | 37 | 89 | 141 | 193 | 246 | 299 | 351 | 404 | 456 | 509 |
| 20.000 | 35 | 84 | 134 | 184 | 234 | 284 | 334 | 384 | 434 | 484 |
| 25.000 | 28 | 67 | 107 | 147 | 187 | 227 | 267 | 307 | 347 | 387 |
| 30.000 | 23 | 56 | 89 | 123 | 156 | 189 | 222 | 256 | 289 | 322 |
| 35.000 | 20 | 48 | 77 | 105 | 134 | 162 | 191 | 219 | 248 | 276 |
| 40.000 | 18 | 42 | 67 | 92 | 117 | 142 | 167 | 192 | 217 | 242 |
| 45.000 | 16 | 37 | 60 | 82 | 104 | 126 | 148 | 170 | 193 | 215 |
| 50.000 | 14 | 34 | 54 | 74 | 93 | 113 | 133 | 153 | 173 | 193 |
| 55.000 | 13 | 31 | 49 | 67 | 85 | 103 | 121 | 139 | 158 | 176 |
| 60.000 | 12 | 28 | 45 | 61 | 78 | 95 | 111 | 128 | 145 | 161 |
| 65.000 | 11 | 26 | 41 | 57 | 72 | 87 | 103 | 118 | 133 | 149 |
| 70.000 | 10 | 24 | 38 | 53 | 67 | 81 | 95 | 110 | 124 | 138 |
| 75.000 | 9.4 | 22 | 36 | 49 | 62 | 76 | 89 | 102 | 116 | 129 |
| 80.000 | 8.8 | 21 | 33 | 46 | 58 | 71 | 83 | 96 | 108 | 121 |
| 85.000 | 8.3 | 20 | 32 | 43 | 55 | 67 | 78 | 90 | 102 | 114 |
| 90.000 | 7.8 | 19 | 30 | 41 | 52 | 63 | 74 | 85 | 96 | 107 |
| 95.000 | 7.4 | 18 | 28 | 39 | 49 | 60 | 70 | 81 | 91 | 102 |
| 100.000 | 7.0 | 17 | 27 | 37 | 47 | 57 | 67 | 77 | 87 | 97 |
| 105.000 | 6.7 | 16 | 26 | 35 | 45 | 54 | 64 | 73 | 83 | 92 |
| 110.000 | 6.4 | 15 | 24 | 33 | 42 | 52 | 61 | 70 | 79 | 88 |
| 120.000 | 5.9 | 14 | 22 | 31 | 39 | 47 | 56 | 64 | 72 | 81 |
| 130.000 | 5.4 | 13 | 21 | 28 | 36 | 44 | 51 | 59 | 67 | 74 |
| 140.000 | 5.0 | 12 | 19 | 26 | 33 | 41 | 48 | 55 | 62 | 69 |
| 150.000 | 4.7 | 11 | 18 | 25 | 31 | 38 | 44 | 51 | 58 | 64 |
| 160.000 | 4.4 | 10.5 | 17 | 23 | 29 | 35 | 42 | 48 | 54 | 60 |
| 170.000 | 4.1 | 9.9 | 16 | 22 | 27 | 33 | 39 | 45 | 51 | 57 |
| 180.000 | 3.9 | 9.4 | 15 | 20 | 26 | 32 | 37 | 43 | 48 | 54 |
| 190.000 | 3.7 | 8.9 | 14 | 19 | 25 | 30 | 35 | 40 | 46 | 51 |
| 200.000 | 3.5 | 8.4 | 13 | 18 | 23 | 28 | 33 | 38 | 43 | 48 |
| 210.000 | 3.3 | 8.0 | 12.8 | 18 | 22 | 27 | 32 | 37 | 41 | 46 |
| 220.000 | 3.2 | 7.7 | 12.2 | 17 | 21 | 26 | 30 | 35 | 39 | 44 |
| 230.000 | 3.1 | 7.3 | 11.6 | 16 | 20 | 25 | 29 | 33 | 38 | 42 |
| 240.000 | 2.9 | 7.0 | 11.2 | 15 | 19 | 24 | 28 | 32 | 36 | 40 |
| 250.000 | 2.8 | 6.7 | 10.7 | 14.7 | 18.7 | 23 | 27 | 31 | 35 | 39 |

N = a unit of product, an opportunity for nonconformities, etc.

r = the number of nonconformities.

| N | r → 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 260.000 | 2.7 | 6.5 | 10.3 | 14.1 | 18.0 | 22 | 26 | 30 | 33 | 37 |
| 270.000 | 2.6 | 6.2 | 9.9 | 13.6 | 17.3 | 21 | 25 | 28 | 32 | 36 |
| 280.000 | 2.5 | 6.0 | 9.6 | 13.1 | 16.7 | 20 | 24 | 27 | 31 | 35 |
| 290.000 | 2.4 | 5.8 | 9.2 | 12.7 | 16.1 | 19.6 | 23 | 26 | 30 | 33 |
| 300.000 | 2.3 | 5.6 | 8.9 | 12.3 | 15.6 | 18.9 | 22 | 26 | 29 | 32 |
| 310.000 | 2.27 | 5.4 | 8.6 | 11.9 | 15.1 | 18.3 | 22 | 25 | 28 | 31 |
| 320.000 | 2.19 | 5.3 | 8.4 | 11.5 | 14.6 | 17.7 | 21 | 24 | 27 | 30 |
| 330.000 | 2.13 | 5.1 | 8.1 | 11.1 | 14.2 | 17.2 | 20 | 23 | 26 | 29 |
| 340.000 | 2.07 | 5.0 | 7.9 | 10.8 | 13.7 | 16.7 | 19.6 | 23 | 26 | 28 |
| 350.000 | 2.01 | 4.8 | 7.7 | 10.5 | 13.4 | 16.2 | 19.1 | 22 | 25 | 28 |
| 360.000 | 1.95 | 4.7 | 7.4 | 10.2 | 13.0 | 15.8 | 18.5 | 21 | 24 | 27 |
| 370.000 | 1.90 | 4.6 | 7.2 | 9.9 | 12.6 | 15.3 | 18.0 | 21 | 23 | 26 |
| 380.000 | 1.85 | 4.4 | 7.0 | 9.7 | 12.3 | 14.9 | 17.6 | 20.2 | 23 | 25 |
| 390.000 | 1.80 | 4.3 | 6.9 | 9.4 | 12.0 | 14.5 | 17.1 | 19.7 | 22 | 25 |
| 400.000 | 1.76 | 4.2 | 6.7 | 9.2 | 11.7 | 14.2 | 16.7 | 19.2 | 22 | 24 |
| 450.000 | 1.56 | 3.7 | 6.0 | 8.2 | 10.4 | 12.6 | 14.8 | 17.0 | 19 | 21 |
| 500.000 | 1.40 | 3.4 | 5.4 | 7.4 | 9.3 | 11.3 | 13.3 | 15.3 | 17 | 19 |
| 550.000 | 1.28 | 3.1 | 4.9 | 6.7 | 8.5 | 10.3 | 12.1 | 13.9 | 16 | 18 |
| 600.000 | 1.17 | 2.8 | 4.5 | 6.1 | 7.8 | 9.5 | 11.1 | 12.8 | 14 | 16 |
| 650.000 | 1.08 | 2.6 | 4.1 | 5.7 | 7.2 | 8.7 | 10.3 | 11.8 | 13 | 15 |
| 700.000 | 1.00 | 2.4 | 3.8 | 5.3 | 6.7 | 8.1 | 9.5 | 11.0 | 12.4 | 14 |
| 750.000 | 0.94 | 2.2 | 3.6 | 4.9 | 6.2 | 7.6 | 8.9 | 10.2 | 11.6 | 13 |
| 800.000 | 0.88 | 2.1 | 3.3 | 4.6 | 5.8 | 7.1 | 8.3 | 9.6 | 10.8 | 12 |
| 850.000 | 0.83 | 2.0 | 3.2 | 4.3 | 5.5 | 6.7 | 7.8 | 9.0 | 10.2 | 11 |
| 900.000 | 0.78 | 1.9 | 3.0 | 4.1 | 5.2 | 6.3 | 7.4 | 8.5 | 9.6 | 10.7 |
| 950.000 | 0.74 | 1.8 | 2.8 | 3.9 | 4.9 | 6.0 | 7.0 | 8.1 | 9.1 | 10.2 |
| 1.000.000 | 0.70 | 1.7 | 2.7 | 3.7 | 4.7 | 5.7 | 6.7 | 7.7 | 8.7 | 9.7 |

N = a unit of product, an opportunity for nonconformities, etc.
r = the number of nonconformities.

## APPENDIX B

### Area under Standard Normal Distribution Curve

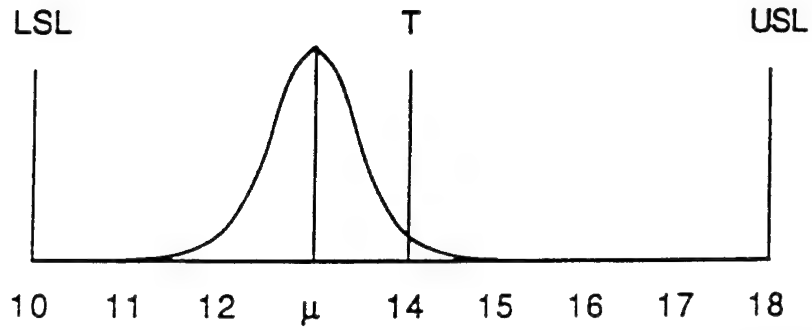
### Beyon a selected value $z$

| Z | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 5.000E-01 | 4.960E-01 | 4.920E-01 | 4.880E-01 | 4.840E-01 | 4.801E-01 | 4.761E-01 | 4.721E-01 | 4.681E-01 | 4.641E-01 |
| 0.10 | 4.602E-01 | 4.562E-01 | 4.522E-01 | 4.483E-01 | 4.443E-01 | 4.404E-01 | 4.364E-01 | 4.325E-01 | 4.286E-01 | 4.247E-01 |
| 0.20 | 4.207E-01 | 4.168E-01 | 4.129E-01 | 4.090E-01 | 4.052E-01 | 4.013E-01 | 3.974E-01 | 3.936E-01 | 3.897E-01 | 3.859E-01 |
| 0.30 | 3.821E-01 | 3.783E-01 | 3.745E-01 | 3.707E-01 | 3.669E-01 | 3.632E-01 | 3.594E-01 | 3.557E-01 | 3.520E-01 | 3.483E-01 |
| 0.40 | 3.446E-01 | 3.409E-01 | 3.372E-01 | 3.336E-01 | 3.300E-01 | 3.264E-01 | 3.228E-01 | 3.192E-01 | 3.156E-01 | 3.121E-01 |
| 0.50 | 3.085E-01 | 3.050E-01 | 3.015E-01 | 2.981E-01 | 2.946E-01 | 2.912E-01 | 2.877E-01 | 2.843E-01 | 2.810E-01 | 2.776E-01 |
| 0.60 | 2.743E-01 | 2.709E-01 | 2.676E-01 | 2.643E-01 | 2.611E-01 | 2.578E-01 | 2.546E-01 | 2.514E-01 | 2.483E-01 | 2.451E-01 |
| 0.70 | 2.420E-01 | 2.389E-01 | 2.358E-01 | 2.327E-01 | 2.297E-01 | 2.266E-01 | 2.236E-01 | 2.207E-01 | 2.177E-01 | 2.148E-01 |
| 0.80 | 2.119E-01 | 2.090E-01 | 2.061E-01 | 2.033E-01 | 2.005E-01 | 1.977E-01 | 1.949E-01 | 1.922E-01 | 1.894E-01 | 1.867E-01 |
| 0.90 | 1.841E-01 | 1.814E-01 | 1.788E-01 | 1.762E-01 | 1.736E-01 | 1.711E-01 | 1.685E-01 | 1.660E-01 | 1.635E-01 | 1.611E-01 |
| 1.00 | 1.587E-01 | 1.562E-01 | 1.539E-01 | 1.515E-01 | 1.492E-01 | 1.469E-01 | 1.446E-01 | 1.423E-01 | 1.401E-01 | 1.379E-01 |
| 1.10 | 1.357E-01 | 1.335E-01 | 1.314E-01 | 1.292E-01 | 1.271E-01 | 1.251E-01 | 1.230E-01 | 1.210E-01 | 1.190E-01 | 1.170E-01 |
| 1.20 | 1.151E-01 | 1.131E-01 | 1.112E-01 | 1.093E-01 | 1.075E-01 | 1.056E-01 | 1.038E-01 | 1.020E-01 | 1.003E-01 | 9.853E-02 |
| 1.30 | 9.680E-02 | 9.510E-02 | 9.342E-02 | 9.176E-02 | 9.012E-02 | 8.851E-02 | 8.691E-02 | 8.534E-02 | 8.379E-02 | 8.226E-02 |
| 1.40 | 8.076E-02 | 7.927E-02 | 7.780E-02 | 7.636E-02 | 7.493E-02 | 7.353E-02 | 7.214E-02 | 7.078E-02 | 6.944E-02 | 6.811E-02 |
| 1.50 | 6.681E-02 | 6.552E-02 | 6.426E-02 | 6.301E-02 | 6.178E-02 | 6.057E-02 | 5.938E-02 | 5.821E-02 | 5.705E-02 | 5.592E-02 |
| 1.60 | 5.480E-02 | 5.370E-02 | 5.262E-02 | 5.155E-02 | 5.050E-02 | 4.947E-02 | 4.846E-02 | 4.746E-02 | 4.648E-02 | 4.551E-02 |
| 1.70 | 4.457E-02 | 4.363E-02 | 4.272E-02 | 4.182E-02 | 4.093E-02 | 4.006E-02 | 3.920E-02 | 3.836E-02 | 3.754E-02 | 3.673E-02 |
| 1.80 | 3.593E-02 | 3.515E-02 | 3.438E-02 | 3.363E-02 | 3.288E-02 | 3.216E-02 | 3.144E-02 | 3.074E-02 | 3.005E-02 | 2.938E-02 |
| 1.90 | 2.872E-02 | 2.807E-02 | 2.743E-02 | 2.680E-02 | 2.619E-02 | 2.559E-02 | 2.500E-02 | 2.442E-02 | 2.385E-02 | 2.330E-02 |
| 2.00 | 2.275E-02 | 2.222E-02 | 2.169E-02 | 2.118E-02 | 2.068E-02 | 2.018E-02 | 1.970E-02 | 1.923E-02 | 1.876E-02 | 1.831E-02 |
| 2.10 | 1.786E-02 | 1.743E-02 | 1.700E-02 | 1.659E-02 | 1.618E-02 | 1.578E-02 | 1.539E-02 | 1.500E-02 | 1.463E-02 | 1.426E-02 |
| 2.20 | 1.390E-02 | 1.355E-02 | 1.321E-02 | 1.287E-02 | 1.255E-02 | 1.222E-02 | 1.191E-02 | 1.160E-02 | 1.130E-02 | 1.101E-02 |
| 2.30 | 1.072E-02 | 1.044E-02 | 1.017E-02 | 9.903E-03 | 9.642E-03 | 9.387E-03 | 9.137E-03 | 8.894E-03 | 8.656E-03 | 8.424E-03 |
| 2.40 | 8.198E-03 | 7.976E-03 | 7.760E-03 | 7.549E-03 | 7.344E-03 | 7.143E-03 | 6.947E-03 | 6.756E-03 | 6.569E-03 | 6.387E-03 |
| 2.50 | 6.210E-03 | 6.036E-03 | 5.868E-03 | 5.703E-03 | 5.543E-03 | 5.386E-03 | 5.234E-03 | 5.085E-03 | 4.940E-03 | 4.799E-03 |
| 2.60 | 4.661E-03 | 4.527E-03 | 4.396E-03 | 4.269E-03 | 4.145E-03 | 4.024E-03 | 3.907E-03 | 3.792E-03 | 3.681E-03 | 3.572E-03 |
| 2.70 | 3.467E-03 | 3.364E-03 | 3.264E-03 | 3.167E-03 | 3.072E-03 | 2.980E-03 | 2.890E-03 | 2.803E-03 | 2.718E-03 | 2.635E-03 |
| 2.80 | 2.555E-03 | 2.477E-03 | 2.401E-03 | 2.327E-03 | 2.256E-03 | 2.186E-03 | 2.118E-03 | 2.052E-03 | 1.988E-03 | 1.926E-03 |
| 2.90 | 1.866E-03 | 1.807E-03 | 1.750E-03 | 1.695E-03 | 1.641E-03 | 1.589E-03 | 1.538E-03 | 1.489E-03 | 1.441E-03 | 1.395E-03 |
| 3.00 | 1.350E-03 | 1.306E-03 | 1.264E-03 | 1.223E-03 | 1.183E-03 | 1.144E-03 | 1.107E-03 | 1.070E-03 | 1.035E-03 | 1.001E-03 |
| 3.10 | 9.676E-04 | 9.354E-04 | 9.042E-04 | 8.740E-04 | 8.447E-04 | 8.163E-04 | 7.888E-04 | 7.622E-04 | 7.364E-04 | 7.114E-04 |
| 3.20 | 6.871E-04 | 6.637E-04 | 6.410E-04 | 6.190E-04 | 5.977E-04 | 5.770E-04 | 5.571E-04 | 5.378E-04 | 5.191E-04 | 5.010E-04 |
| 3.30 | 4.835E-04 | 4.665E-04 | 4.501E-04 | 4.343E-04 | 4.189E-04 | 4.041E-04 | 3.898E-04 | 3.759E-04 | 3.625E-04 | 3.495E-04 |
| 3.40 | 3.370E-04 | 3.249E-04 | 3.132E-04 | 3.019E-04 | 2.909E-04 | 2.804E-04 | 2.702E-04 | 2.603E-04 | 2.508E-04 | 2.416E-04 |
| 3.50 | 2.327E-04 | 2.242E-04 | 2.159E-04 | 2.079E-04 | 2.002E-04 | 1.927E-04 | 1.855E-04 | 1.786E-04 | 1.719E-04 | 1.655E-04 |
| 3.60 | 1.592E-04 | 1.532E-04 | 1.474E-04 | 1.418E-04 | 1.364E-04 | 1.312E-04 | 1.262E-04 | 1.214E-04 | 1.167E-04 | 1.123E-04 |
| 3.70 | 1.079E-04 | 1.038E-04 | 9.974E-05 | 9.587E-05 | 9.214E-05 | 8.855E-05 | 8.509E-05 | 8.175E-05 | 7.854E-05 | 7.545E-05 |
| 3.80 | 7.248E-05 | 6.961E-05 | 6.685E-05 | 6.420E-05 | 6.165E-05 | 5.919E-05 | 5.682E-05 | 5.455E-05 | 5.236E-05 | 5.025E-05 |
| 3.90 | 4.822E-05 | 4.627E-05 | 4.440E-05 | 4.260E-05 | 4.086E-05 | 3.920E-05 | 3.760E-05 | 3.606E-05 | 3.458E-05 | 3.316E-05 |
| 4.00 | 3.179E-05 | 3.048E-05 | 2.921E-05 | 2.800E-05 | 2.684E-05 | 2.572E-05 | 2.465E-05 | 2.362E-05 | 2.263E-05 | 2.168E-05 |
| 4.10 | 2.076E-05 | 1.989E-05 | 1.905E-05 | 1.824E-05 | 1.747E-05 | 1.672E-05 | 1.601E-05 | 1.533E-05 | 1.467E-05 | 1.404E-05 |
| 4.20 | 1.344E-05 | 1.286E-05 | 1.231E-05 | 1.177E-05 | 1.126E-05 | 1.077E-05 | 1.031E-05 | 9.857E-06 | 9.426E-06 | 9.014E-06 |
| 4.30 | 8.619E-06 | 8.240E-06 | 7.878E-06 | 7.530E-06 | 7.198E-06 | 6.879E-06 | 6.574E-06 | 6.282E-06 | 6.002E-06 | 5.734E-06 |
| 4.40 | 5.478E-06 | 5.233E-06 | 4.998E-06 | 4.773E-06 | 4.558E-06 | 4.353E-06 | 4.156E-06 | 3.968E-06 | 3.787E-06 | 3.615E-06 |
| 4.50 | 3.451E-06 | 3.293E-06 | 3.143E-06 | 2.999E-06 | 2.861E-06 | 2.730E-06 | 2.604E-06 | 2.484E-06 | 2.369E-06 | 2.259E-06 |
| 4.60 | 2.154E-06 | 2.054E-06 | 1.959E-06 | 1.867E-06 | 1.780E-06 | 1.697E-06 | 1.617E-06 | 1.541E-06 | 1.469E-06 | 1.399E-06 |
| 4.70 | 1.333E-06 | 1.270E-06 | 1.210E-06 | 1.153E-06 | 1.098E-06 | 1.046E-06 | 9.956E-07 | 9.480E-07 | 9.026E-07 | 8.593E-07 |
| 4.80 | 8.181E-07 | 7.787E-07 | 7.411E-07 | 7.054E-07 | 6.712E-07 | 6.387E-07 | 6.077E-07 | 5.782E-07 | 5.500E-07 | 5.233E-07 |
| 4.90 | 4.976E-07 | 4.733E-07 | 4.501E-07 | 4.280E-07 | 4.070E-07 | 3.869E-07 | 3.678E-07 | 3.496E-07 | 3.323E-07 | 3.159E-07 |

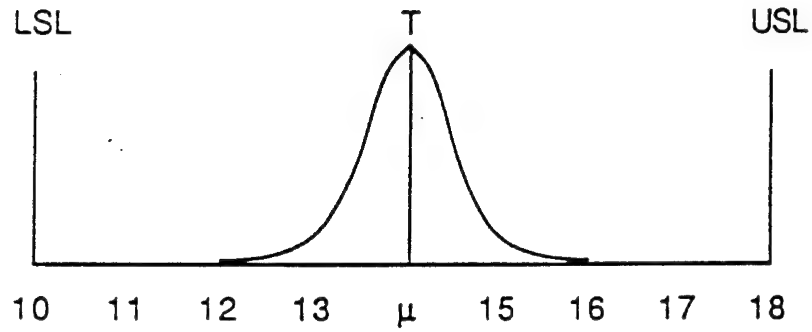
| Z | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5.00 | 3.002E-07 | 2.853E-07 | 2.711E-07 | 2.575E-07 | 2.447E-07 | 2.324E-07 | 2.208E-07 | 2.097E-07 | 1.991E-07 | 1.891E-07 |
| 5.10 | 1.796E-07 | 1.705E-07 | 1.619E-07 | 1.537E-07 | 1.459E-07 | 1.385E-07 | 1.314E-07 | 1.247E-07 | 1.184E-07 | 1.123E-07 |
| 5.20 | 1.066E-07 | 1.011E-07 | 9.591E-08 | 9.098E-08 | 8.629E-08 | 8.184E-08 | 7.762E-08 | 7.360E-08 | 6.979E-08 | 6.617E-08 |
| 5.30 | 6.273E-08 | 5.947E-08 | 5.637E-08 | 5.343E-08 | 5.064E-08 | 4.799E-08 | 4.548E-08 | 4.309E-08 | 4.083E-08 | 3.868E-08 |
| 5.40 | 3.664E-08 | 3.471E-08 | 3.288E-08 | 3.114E-08 | 2.949E-08 | 2.792E-08 | 2.644E-08 | 2.503E-08 | 2.370E-08 | 2.244E-08 |
| 5.50 | 2.124E-08 | 2.010E-08 | 1.903E-08 | 1.801E-08 | 1.704E-08 | 1.613E-08 | 1.526E-08 | 1.444E-08 | 1.366E-08 | 1.292E-08 |
| 5.60 | 1.222E-08 | 1.156E-08 | 1.093E-08 | 1.034E-08 | 9.776E-09 | 9.244E-09 | 8.741E-09 | 8.264E-09 | 7.812E-09 | 7.385E-09 |
| 5.70 | 6.980E-09 | 6.598E-09 | 6.235E-09 | 5.893E-09 | 5.568E-09 | 5.262E-09 | 4.971E-09 | 4.697E-09 | 4.437E-09 | 4.191E-09 |
| 5.80 | 3.959E-09 | 3.739E-09 | 3.532E-09 | 3.335E-09 | 3.150E-09 | 2.974E-09 | 2.808E-09 | 2.651E-09 | 2.503E-09 | 2.363E-09 |
| 5.90 | 2.230E-09 | 2.105E-09 | 1.987E-09 | 1.875E-09 | 1.769E-09 | 1.670E-09 | 1.576E-09 | 1.487E-09 | 1.402E-09 | 1.323E-09 |
| 6.00 | 1.248E-09 | 1.177E-09 | 1.110E-09 | 1.047E-09 | 9.876E-10 | 9.314E-10 | 8.783E-10 | 8.281E-10 | 7.808E-10 | 7.361E-10 |
| 6.10 | 6.940E-10 | 6.542E-10 | 6.166E-10 | 5.812E-10 | 5.478E-10 | 5.163E-10 | 4.865E-10 | 4.585E-10 | 4.320E-10 | 4.070E-10 |
| 6.20 | 3.835E-10 | 3.613E-10 | 3.403E-10 | 3.206E-10 | 3.020E-10 | 2.844E-10 | 2.679E-10 | 2.523E-10 | 2.376E-10 | 2.237E-10 |
| 6.30 | 2.107E-10 | 1.983E-10 | 1.867E-10 | 1.758E-10 | 1.655E-10 | 1.558E-10 | 1.466E-10 | 1.380E-10 | 1.299E-10 | 1.223E-10 |
| 6.40 | 1.151E-10 | 1.083E-10 | 1.019E-10 | 9.586E-11 | 9.020E-11 | 8.486E-11 | 7.983E-11 | 7.510E-11 | 7.064E-11 | 6.645E-11 |
| 6.50 | 6.250E-11 | 5.878E-11 | 5.529E-11 | 5.199E-11 | 4.889E-11 | 4.597E-11 | 4.323E-11 | 4.065E-11 | 3.821E-11 | 3.593E-11 |
| 6.60 | 3.377E-11 | 3.175E-11 | 2.984E-11 | 2.805E-11 | 2.637E-11 | 2.478E-11 | 2.329E-11 | 2.189E-11 | 2.057E-11 | 1.933E-11 |
| 6.70 | 1.816E-11 | 1.706E-11 | 1.603E-11 | 1.506E-11 | 1.415E-11 | 1.329E-11 | 1.249E-11 | 1.173E-11 | 1.102E-11 | 1.035E-11 |
| 6.80 | 9.719E-12 | 9.127E-12 | 8.572E-12 | 8.049E-12 | 7.559E-12 | 7.097E-12 | 6.664E-12 | 6.257E-12 | 5.874E-12 | 5.515E-12 |
| 6.90 | 5.178E-12 | 4.860E-12 | 4.562E-12 | 4.283E-12 | 4.020E-12 | 3.773E-12 | 3.541E-12 | 3.323E-12 | 3.119E-12 | 2.927E-12 |
| 7.00 | 2.747E-12 | 2.577E-12 | 2.418E-12 | 2.269E-12 | 2.129E-12 | 1.997E-12 | 1.874E-12 | 1.758E-12 | 1.649E-12 | 1.547E-12 |
| 7.10 | 1.451E-12 | 1.361E-12 | 1.277E-12 | 1.198E-12 | 1.123E-12 | 1.053E-12 | 9.879E-13 | 9.264E-13 | 8.688E-13 | 8.147E-13 |
| 7.20 | 7.639E-13 | 7.163E-13 | 6.716E-13 | 6.297E-13 | 5.904E-13 | 5.535E-13 | 5.189E-13 | 4.864E-13 | 4.560E-13 | 4.275E-13 |
| 7.30 | 4.007E-13 | 3.756E-13 | 3.520E-13 | 3.300E-13 | 3.092E-13 | 2.898E-13 | 2.716E-13 | 2.546E-13 | 2.386E-13 | 2.235E-13 |
| 7.40 | 2.095E-13 | 1.963E-13 | 1.839E-13 | 1.723E-13 | 1.615E-13 | 1.513E-13 | 1.417E-13 | 1.328E-13 | 1.244E-13 | 1.166E-13 |
| 7.50 | 1.092E-13 | 1.023E-13 | 9.581E-14 | 8.975E-14 | 8.407E-14 | 7.874E-14 | 7.375E-14 | 6.908E-14 | 6.470E-14 | 6.060E-14 |
| 7.60 | 5.675E-14 | 5.315E-14 | 4.977E-14 | 4.661E-14 | 4.365E-14 | 4.087E-14 | 3.827E-14 | 3.584E-14 | 3.356E-14 | 3.142E-14 |
| 7.70 | 2.942E-14 | 2.755E-14 | 2.579E-14 | 2.415E-14 | 2.261E-14 | 2.116E-14 | 1.981E-14 | 1.855E-14 | 1.736E-14 | 1.625E-14 |
| 7.80 | 1.522E-14 | 1.424E-14 | 1.333E-14 | 1.248E-14 | 1.168E-14 | 1.093E-14 | 1.023E-14 | 9.579E-15 | 8.965E-15 | 8.391E-15 |
| 7.90 | 7.853E-15 | 7.349E-15 | 6.878E-15 | 6.437E-15 | 6.024E-15 | 5.637E-15 | 5.275E-15 | 4.937E-15 | 4.620E-15 | 4.323E-15 |
| 8.00 | 4.045E-15 | 3.785E-15 | 3.542E-15 | 3.314E-15 | 3.101E-15 | 2.901E-15 | 2.715E-15 | 2.540E-15 | 2.376E-15 | 2.223E-15 |
| 8.10 | 2.080E-15 | 1.946E-15 | 1.821E-15 | 1.703E-15 | 1.593E-15 | 1.491E-15 | 1.395E-15 | 1.305E-15 | 1.220E-15 | 1.142E-15 |
| 8.20 | 1.068E-15 | 9.991E-16 | 9.346E-16 | 8.742E-16 | 8.177E-16 | 7.649E-16 | 7.155E-16 | 6.692E-16 | 6.260E-16 | 5.855E-16 |
| 8.30 | 5.477E-16 | 5.122E-16 | 4.791E-16 | 4.481E-16 | 4.191E-16 | 3.920E-16 | 3.666E-16 | 3.429E-16 | 3.207E-16 | 2.999E-16 |
| 8.40 | 2.805E-16 | 2.624E-16 | 2.454E-16 | 2.295E-16 | 2.146E-16 | 2.007E-16 | 1.877E-16 | 1.755E-16 | 1.642E-16 | 1.535E-16 |
| 8.50 | 1.436E-16 | 1.342E-16 | 1.255E-16 | 1.174E-16 | 1.098E-16 | 1.027E-16 | 9.601E-17 | 8.978E-17 | 8.395E-17 | 7.851E-17 |
| 8.60 | 7.341E-17 | 6.865E-17 | 6.419E-17 | 6.003E-17 | 5.613E-17 | 5.249E-17 | 4.908E-17 | 4.589E-17 | 4.291E-17 | 4.013E-17 |
| 8.70 | 3.752E-17 | 3.508E-17 | 3.281E-17 | 3.068E-17 | 2.868E-17 | 2.682E-17 | 2.508E-17 | 2.345E-17 | 2.193E-17 | 2.050E-17 |
| 8.80 | 1.917E-17 | 1.792E-17 | 1.676E-17 | 1.567E-17 | 1.465E-17 | 1.370E-17 | 1.281E-17 | 1.198E-17 | 1.120E-17 | 1.047E-17 |
| 8.90 | 9.792E-18 | 9.155E-18 | 8.560E-18 | 8.004E-18 | 7.484E-18 | 6.998E-18 | 6.543E-18 | 6.118E-18 | 5.720E-18 | 5.349E-18 |
| 9.00 | 5.001E-18 | 4.676E-18 | 4.372E-18 | 4.088E-18 | 3.823E-18 | 3.574E-18 | 3.342E-18 | 3.125E-18 | 2.922E-18 | 2.732E-18 |
| 9.10 | 2.555E-18 | 2.389E-18 | 2.234E-18 | 2.089E-18 | 1.953E-18 | 1.826E-18 | 1.707E-18 | 1.597E-18 | 1.493E-18 | 1.396E-18 |
| 9.20 | 1.305E-18 | 1.221E-18 | 1.141E-18 | 1.067E-18 | 9.979E-19 | 9.332E-19 | 8.726E-19 | 8.160E-19 | 7.630E-19 | 7.135E-19 |
| 9.30 | 6.672E-19 | 6.239E-19 | 5.834E-19 | 5.456E-19 | 5.102E-19 | 4.771E-19 | 4.462E-19 | 4.172E-19 | 3.902E-19 | 3.649E-19 |
| 9.40 | 3.412E-19 | 3.191E-19 | 2.984E-19 | 2.791E-19 | 2.610E-19 | 2.441E-19 | 2.283E-19 | 2.135E-19 | 1.996E-19 | 1.867E-19 |
| 9.50 | 1.746E-19 | 1.633E-19 | 1.527E-19 | 1.428E-19 | 1.336E-19 | 1.250E-19 | 1.169E-19 | 1.093E-19 | 1.022E-19 | 9.562E-20 |
| 9.60 | 8.943E-20 | 8.365E-20 | 7.824E-20 | 7.318E-20 | 6.845E-20 | 6.402E-20 | 5.988E-20 | 5.601E-20 | 5.240E-20 | 4.901E-20 |
| 9.70 | 4.584E-20 | 4.288E-20 | 4.011E-20 | 3.752E-20 | 3.510E-20 | 3.284E-20 | 3.072E-20 | 2.873E-20 | 2.688E-20 | 2.515E-20 |
| 9.80 | 2.352E-20 | 2.201E-20 | 2.059E-20 | 1.926E-20 | 1.802E-20 | 1.686E-20 | 1.577E-20 | 1.476E-20 | 1.381E-20 | 1.292E-20 |
| 9.90 | 1.209E-20 | 1.131E-20 | 1.058E-20 | 9.898E-21 | 9.262E-21 | 8.666E-21 | 8.108E-21 | 7.587E-21 | 7.099E-21 | 6.643E-21 |
| 10.00 | 6.216E-21 | 5.817E-21 | 5.443E-21 | 5.093E-21 | 4.766E-21 | 4.460E-21 | 4.174E-21 | 3.906E-21 | 3.655E-21 | 3.421E-21 |

## APPENDIX C

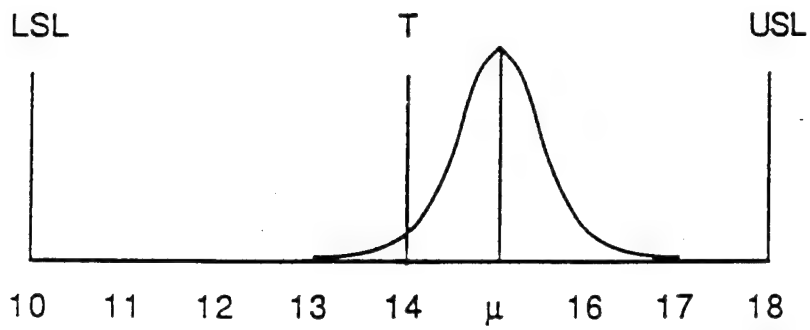
### Comparson among Four PCI measures



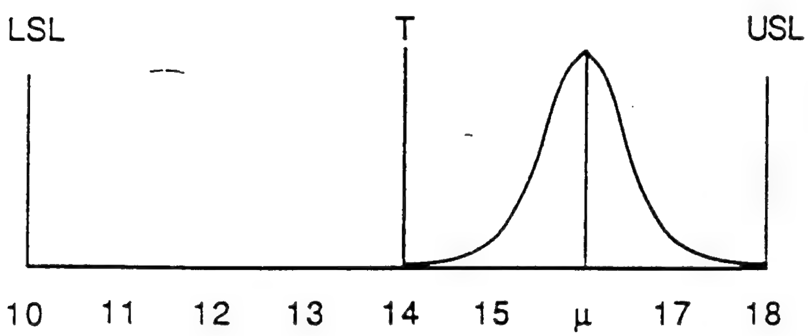

| μ | Cp | CPL | CPU | Cpk | Cpm |
|---|---|---|---|---|---|
| 13 | 2 | 1.5 | 2.5 | 1.5 | 1.11 |



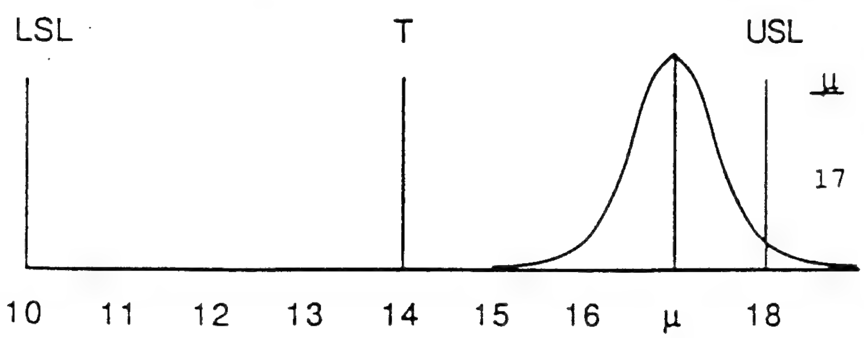

| μ | Cp | CPL | CPU | Cpk | Cpm |
|---|---|---|---|---|---|
| 14 | 2 | 2.0 | 2.0 | 2.0 | 2.00 |




| μ | Cp | CPL | CPU | Cpk | Cpm |
|---|---|---|---|---|---|
| 15 | 2 | 2.5 | 1.5 | 1.5 | 1.11 |

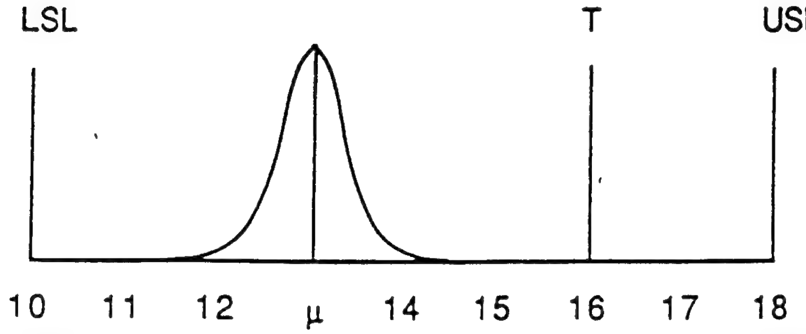



| μ | Cp | CPL | CPU | Cpk | Cpm |
|---|---|---|---|---|---|
| 16 | 2 | 3.0 | 1.0 | 1.0 | 0.63 |

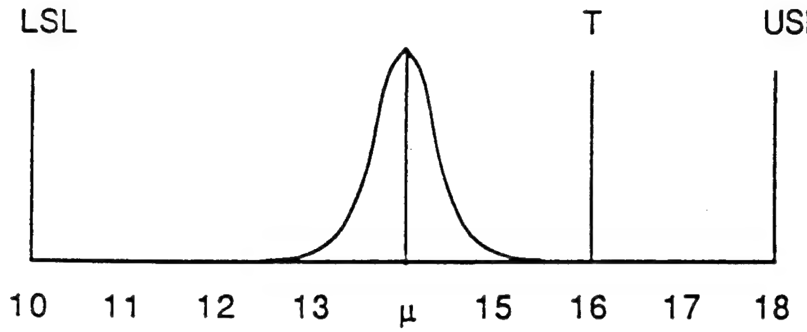



| μ | Cp | CPL | CPU | Cpk | Cpm |
|---|---|---|---|---|---|
| 17 | 2 | 3.5 | 0.5 | 0.5 | 0.43 |

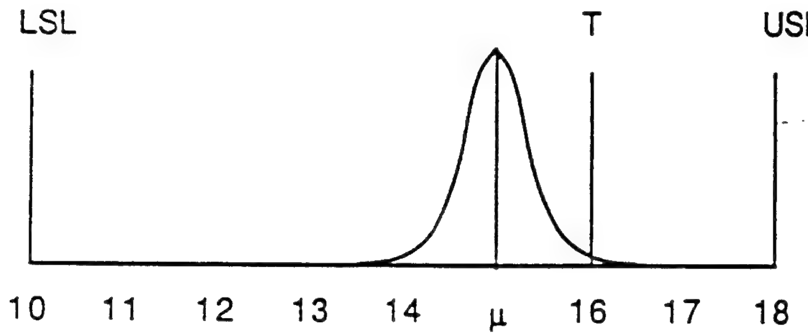
Comparisons of $C_p$, $C_{pk}$, CPU, CPL, and $C_{pm}$ with $(USL - T) = (T - LSL)$.



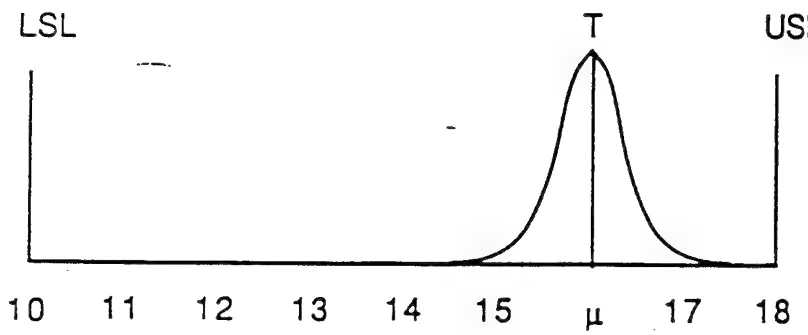

| μ | CPL | CPU | Cpk | Cpm* |
|---|---|---|---|---|
| 13 | 1.5 | 0 | 0 | 0.22 |



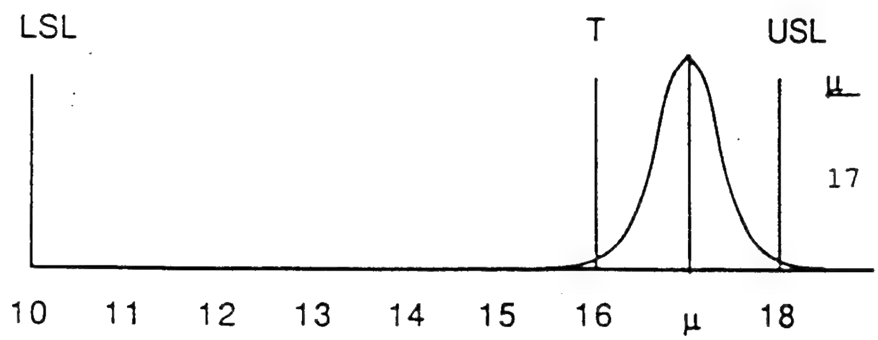

| μ | CPL | CPU | Cpk | Cpm* |
|---|---|---|---|---|
| 14 | 2.0 | 0 | 0 | 0.32 |




| μ | CPL | CPU | Cpk | Cpm* |
|---|---|---|---|---|
| 15 | 2.5 | 0.5 | 0.5 | 0.56 |




| μ | CPL | CPU | Cpk | Cpm* |
|---|---|---|---|---|
| 16 | 3.0 | 1.0 | 1.0 | 1.00 |




| μ | CPL | CPU | Cpk | Cpm* |
|---|---|---|---|---|
| 17 | 2.5 | 0.5 | 0.5 | 0.56 |

Comparisons of $C_{pk}$, CPU, CPL, and $C_{pm}^*$ with (USL − $T$) ≠ ($T$ − LSL).

# APPENDIX D

## SpreadSheet: Cost Analysis for Pouch Forming Design C

# Production Schedule

| | |
|---|---|
| Hours/Shift | 8 |
| Shifts/Day | 1 |
| Days/Week | 5 |
| Weeks/Year | 48 |
| Hours/Year | 1920 |
| | |
| Production Rate MRE Line | |
| Units/Minute | 102 |
| | |
| Avg Unit Fill&Seal/Hour | 4,651 |
| Avg Unit for Fill / Hour with reworl | 4,455 |
| Avg Unit FP Output Rate/Hour | 4,250 |
| Daily Unit Rate | 34,001 |
| Annual Output from Final Inspect | 8,242,671 |
| Annualized Unit Rate | 8,160,244 |
| Annual Requirement | 5,000,000 |
| Plant Utilization | 61.27% |

# Process Yield & Efficiency

| | Efficiency | Yield | |
|---|---|---|---|
| Product Preparation Equipm. | 90.0% | 95.0% | (yield of gravy system) |
| Filling Equipment | 95.0% | 97.0% | (avg yield of product) |
| Horizontal Form & Seal Equipmei | 80.0% | 90.0% | (yield of packaging materia |
| Pouch Packaging System | 76.0% | | |
| First Inspection Equipment | 90.0% | 92.3% | (% accepted pouches) |
| Rework System | 80.0% | 95.0% | |
| Rack Loading Equipment | 90.0% | 100.0% | |
| Retort Equipment | 90.0% | 100.0% | |
| Rack Unloading Equipment | 90.0% | 100.0% | |
| Final Inspection Equipment | 90.0% | 100.0% | (% accepted pouches) |
| Final Packaging Equipment | 70.0% | 99.0% | (% yield including qc samp |

| Process Design Capacity | Rated Capacity | Output Expected | |
|---|---|---|---|
| Product Preparation Equipment | 86.6 | 74.1 | pouches/min |
| Filling Equipment | 102.0 | 77.5 | pouches/min |
| Horizontal Form & Seal Equipmei | 102.0 | 77.5 | pouches/min |
| First Inspection Equipment | 113.3 | 71.6 | inspections/min |
| Rework System | 9.8 | 5.7 | |
| Rack Loading Equipment | 113.3 | 71.6 | pouches/min |
| Retort Equipment | 113.3 | 71.6 | pouches/min |
| Rack Unloading Equipment | 113.3 | 71.6 | pouches/min |
| Final Inspection Equipment | 113.3 | 71.6 | inspections/min |
| Final Packaging Equipment | 145.7 | 70.8 | pouches/min |

# Material Data Cost Sheet

| Product Ingredient | Formula | % Formula | Preparation Yield% | Cost/lb | Cost/Lb | Fat Cont% | Salt Cont% | Drain Wt. Yield% |
|---|---|---|---|---|---|---|---|---|
| Gravy | 96.46 | 41.80% | 95.00% | $0.15 | $0.066 | 3.60% | 0.12% | |
| Beef Fill Wt | 83.33 | 36.11% | 95.00% | $2.00 | $0.760 | 0.65% | 2.36% | 85.00% |
| Veg. Fill Wt | 50.98 | 22.09% | | | | | | 135.00% |
| Potato | 21.300836 | 9.23% | 95.00% | $0.70 | $0.068 | | | |
| Carrots | 21.300836 | 9.23% | 95.00% | $0.65 | $0.063 | | | |
| Peas | 8.3783287 | 3.63% | 95.00% | $0.85 | $0.032 | | | |
| | ========= | ========= | | | ========= | | | |
| | 230.77 | 100.00% | | | $0.990 | | | |

| | | |
|---|---|---|
| Avg Target Fill Weight | [gram] | 230.77 |
| | [lb] | 0.5096511 |
| | **Product Cost/Containe** | **$0.504** |

Packaging Material

| | $/m | pouches/m | % yield | $/pouch |
|---|---|---|---|---|
| Top Film | $0.71 | 16.528926 | 90.0% | $0.048 |
| Bottom Film | $0.71 | 16.528926 | 90.0% | $0.048 |
| | | | | ========= |
| | | **Pouch Cost** | | **$0.096** |

| | $/unit | pouch/unit | % yield | $/pouch |
|---|---|---|---|---|
| Carton | $0.07 | 1 | 99.00% | $0.074 |
| Case | $0.34 | 72 | 99.00% | $0.005 |
| Inserts | $0.23 | 72 | 99.00% | $0.003 |
| Pallet | $10.00 | 2880 | 99.00% | $0.003 |
| | | | | ========= |
| | | **FP Packaging Cost** | | **$0.085** |

# Labor Cost Estimate

| | | Rate | Wages |
|---|---|---|---|
| Warehouse Labor | 2 | $10.00 | $20.00 |
| Gravy Prep Labor | 1 | $10.00 | $10.00 |
| Filling Labor | 1 | $10.00 | $10.00 |
| Packaging Labor | 1 | $15.00 | $15.00 |
| First Inspection | 6 | $10.00 | $60.00 |
| Rework Labor | 1 | $10.00 | $10.00 |
| Rack Loading | 4 | $10.00 | $40.00 |
| Retort Labor | 2 | $15.00 | $30.00 |
| Rack Unloading & Washing | 3 | $10.00 | $30.00 |
| Final Inspection Labor | 12 | $10.00 | $120.00 |
| Finished Product Packaging | 2 | $10.00 | $20.00 |
| Cleaning Labor | 3 | $10.00 | $30.00 |
| | ========= | ========= | =========== |
| Total Labor / Hr | 38 | | $395.00 |
| | | | |
| Annual Opperating Labor Cost | | | $758,400.00 |
| Direct Supervisory and Clerical l | 15.00% OL | | $113,760 |
| Quality Control | 15.00% OL | | $113,760 |
| | | | =========== |
| Total Annual Labor Cost | | | $985,920 |

| Assumptions Labor: | sec/inspec | inspector |
|---|---|---|
| First Inspection Time | 3 | 5.7 |
| Second Inspection Time | 6 | 11.3 |
| | p/man/min | man |
| Rack Loading | 30 | 3.8 |
| Rack Unloading | 40 | 2.8 |
| | p/man/min | |
| Rework Labor | 10 | 1.0 |

# Capital Equipment

| | | |
|---|---|---|
| Warehouse Equipment | | $100,000.00 |
| Gravy Preparation Equipment | | $100,000.00 |
| Filling Equipment | | $150,000.00 |
| Horizontal Form Fill Seal Equipment | | $350,000.00 |
| First Inspection Equipment | | $10,000.00 |
| Rack Loading Equipment | | $40,000.00 |
| Retort Equipment | | $940,000.00 |
| Rack Unloading Equipment | | $40,000.00 |
| Final Inspection Equipment | | $10,000.00 |
| Final Packaging Equipment | | $300,000.00 |
| | | =========== |
| **Total Purchased Equipment (PEC)** | | $2,040,000.00 |
| Installation | 45.00% PEC | $918,000.00 |
| Instrumentation | 9.00% PEC | $183,600.00 |
| Piping | 10.00% PEC | $204,000.00 |
| Electrical | 10.00% PEC | $204,000.00 |
| Service Facility | 40.00% PEC | $816,000.00 |
| Engineering & Supervision | 33.00% PEC | $673,200.00 |
| | | =========== |
| **Total Direct Plant Cost (DPC)** | | $5,038,800.00 |
| Contingency | 25.00% DPC | $1,259,700.00 |
| | | =========== |
| **Fixed Capital Investement (FCI)** | | $6,298,500.00 |
| Working Capital | 15.00% TCI | $1,111,500.00 |
| | | =========== |
| **Total Capital Investement (TCI)** | | **$7,410,000.00** |

| | | |
|---|---|---|
| Assumptions Retort | | |
| Containers/Rack | 21 | |
| Rack/Crate | 27 | |
| Crate/Retort | 4 | |
| Retort Load [container/retort] | 2268 | |
| Retort Cycle Time [min] | 75 | |
| Retort Capacity [cont/min] | 30.24 | |
| Number of Retorts | 4 | |
| Cost one retort | $235,000.00 | |
| Budget cost one 1100 retort | $178,000.00 | rotating |
| Budget cost ome 1300 retort | $235,000.00 | rotating |

# Utility Cost Estimate

| Equipment | Gas [ft3/hr] | Water (P) [gal/hr] | Water (C) [gal/hr] | Steam [lb/hr] | Air [ft3/hr] | Electric [kW] |
|---|---|---|---|---|---|---|
| Warehouse | 0 | 0 | 0 | 0 | 0 | 25 |
| Gravy Prep | 0 | 200 | 200 | 500 | 0 | 5 |
| Filling | 0 | 0 | 0 | 0 | 10 | 10 |
| Packaging | 0 | 0 | 50 | 0 | 1000 | 20 |
| Retorting | 0 | 0 | 10000 | 3000 | 100 | 15 |
| FP Packaging | 0 | 0 | 0 | 0 | 0 | 10 |
| Total | 0 | 200 | 10250 | 3500 | 1110 | 85 |

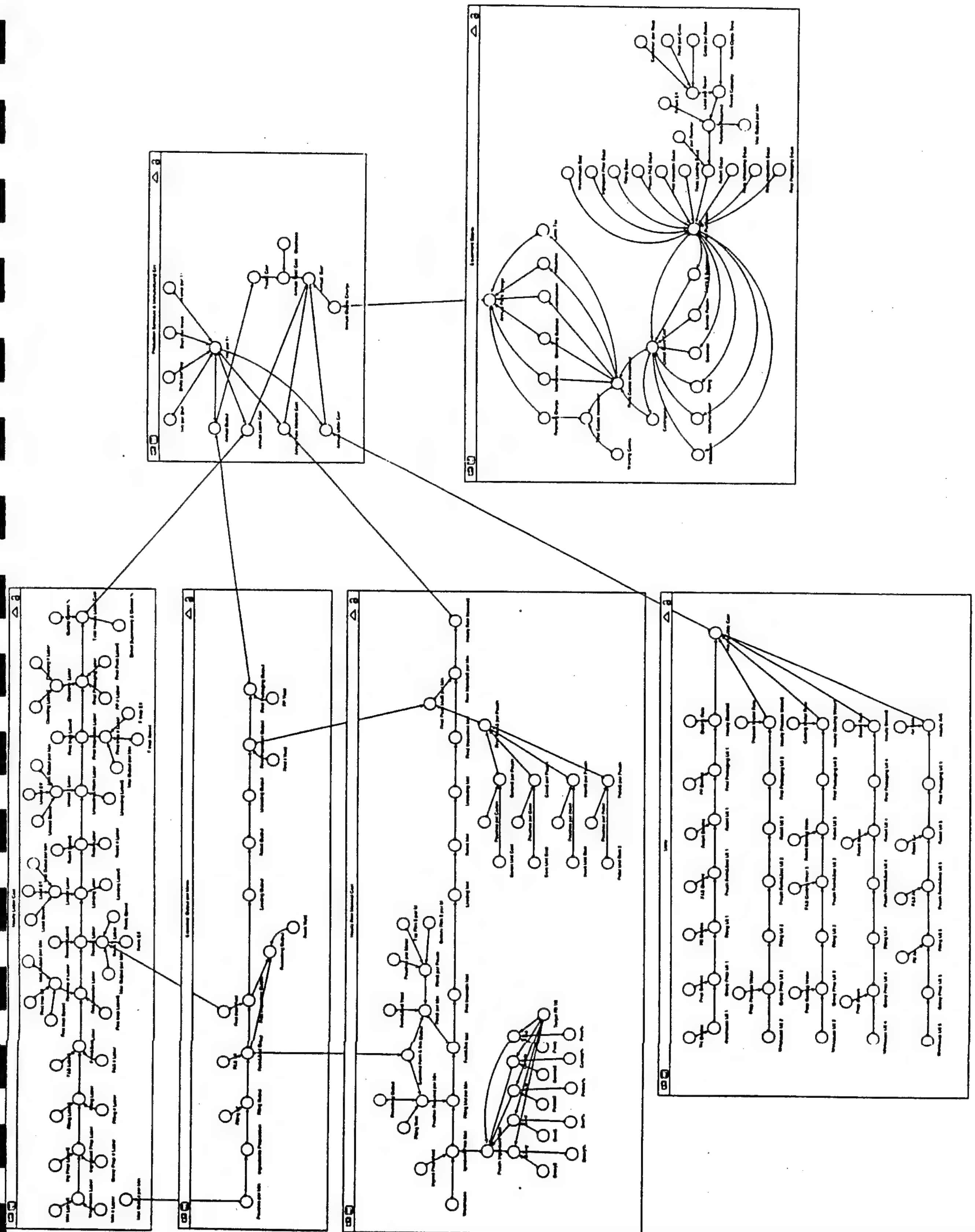
| | Units | Usage | Cost/Unit | $/Hr |
|---|---|---|---|---|
| Natural Gas | [ft3/hr] | 0 | $0.0050 | $0.000 |
| Process Water | [gal/hr] | 200 | $0.0010 | $0.200 |
| Cooling Water | [gal/hr] | 10250 | $0.0003 | $3.075 |
| Steam | [lb/hr] | 3500 | $0.0070 | $24.500 |
| Compressed Air | [ft3/hr] | 1110 | $0.0004 | $0.444 |
| Electric | [kW] | 85 | $0.0900 | $7.650 |
| Energy Cost per Hour | | | | $35.869 |
| Annual Energy Cost | | | | $68,868.480 |

# Manufacturing Cost

| Direct Production Cost | | Annual Cost |
|---|---|---|
| Raw Materials | | $4,314,934 |
| Pouch Packaging Cost | | $857,593 |
| Carton & Case Cost | | $703,832 |
| Total Annual Labor Cost | | $985,920 |
| Utilities | | $68,868 |
| | | ============== |
| Total Direct Production Cost | | $6,931,148 |
| | | |
| **Fixed Charges** | | |
| Depreciation | 10.00% FCI | $629,850 |
| Maintenance and Repair | 6.00% FCI | $377,910 |
| Operating Supplies | 1.00% FCI | $62,985 |
| Local taxes | 4.00% FCI | $251,940 |
| Insurance | 1.00% FCI | $62,985 |
| Financing Cost | 9.00% TCI | $666,900 |
| Rent | | |
| | | ============== |
| **Total Fixed Charges** | | $2,052,570 |
| | | |
| Total Plant Overhead | 7.00% TMC | $676,194 |
| | | ============== |
| **Total Manufacturing Cost (TMC)** | | $9,659,911 |
| | | |
| **Manufacturing Cost per Packaging Unit** | | **$1.18** |

## APPENDIX E

### Visual Representation: Cost Analysis for Beef Stew Pouches



**Equipment Capital**

- $_per_Retorter = 235000.00
- Annual_Plant_Charge = Depreciation+Financing_Charge+Insurance+Local_Tax+Maintenance+Operating_Supplies
- Container__per_Rack = 21
- Contingency = Direct_Plant_Cost*0.25
- Crate_per_Retort = 4
- Depreciation = 0.10*Fixed_Capital_Investment
- Direct_Plant_Cost = Total_Purchase+Electrical++Eng'g_&_Supervise+•Installation+Instrumentation+Piping+Service_Facility
- Electrical = Total_Purchase*0.10
- Eng'g_&_Supervise = Total_Purchase*0.33
- Filling_Equip = 350000
- Final_Inspection_Equip = 10000.00
- Final_Packaging_Equip = 300000.00
- Financing_Charge = 0.09*Total_Capital_Investment
- First_Inspectin_Equip = 0.00
- Fixed_Capital_Investment = Contingency+Direct_Plant_Cost
- Ingregient_Prep_Equip = 100000.00
- Installation = Total_Purchase*.45
- Instrumentation = Total_Purchase*0.09
- Insurance = 0.01*Fixed_Capital_Investment
- Load_per_Retort = Container__per_Rack*Crate_per_Retort*Rack_per_Crate
- Local_Tax = 0.04*Fixed_Capital_Investment
- Maintenance = 0.06*Fixed_Capital_Investment
- Operating_Supplies = 0.01*Fixed_Capital_Investment
- Piping = Total_Purchase*0.10
- Pouch_F&S_Equip = 540000
- Rack_Loading_Equip = 40000.00
- Rack_per_Crate = 27
- Rack_Unloading_Equip = 40000.00

Retorters_Required = ROUND(Max_Output_per_Min/Retort_Capacity/Retort_Eff+0.5)
Retort_Capacity = Load_per_Retort/Retort_Cycle_Time
Retort_Cycle_Time = 75
Retort_Eff = 0.9
Retort_Equip = $_per_Retorter*Retorters_Required
Service_Facility = Total_Purchase*.40

Total_Capital_Investment =
Fixed_Capital_Investment/(1-Working_Capital)*Working_Capital+Fixed_Capital_Investment
Total_Purchase =
Filling_Equip+Final_Inspection_Equip+Final_Packaging_Equip+First_Inspectin_Equip+Ingregient_Prep_Equip+Pouch_F&S_Equip+Rack_Loading_Equip+Rack_Unloading_Equip+Retort_Equip+Warehouse_Eqip

Warehouse_Eqip = 100000.00

Working_Capital = 0.15

**xpected Output per Minite**

F&S_Eff = 0.9

Filling_Eff = 0.95
Filling_Output = Ingredients_Preparation*Filling_Eff
Final_Inspection_Output = Unloading_Output*Final_I_Yield
Final_I_Yield = 0.98

Final_Packaging_Output = Final_Inspection_Output*FP_Yield
First_Inspection_Output = Form&Seal_Output*First_Insp_Yield
First_Insp_Yield = 0.8
Form&Seal_Output = Filling_Output*F&S_Eff
FP_Yield = 0.99
Ingredients_Preparation = Pouches_per_Min
Loading_Output = First_Inspection_Output
Pouches_per_Min = 102

Retort_Output = Loading_Output
Rewk_Yield = 0.8

Reworking_Output = (Form&Seal_Output-First_Inspection_Output)*Rewk_Yield
Unloading_Output = Retort_Output

**ourly Labor Cost**

Cleaning_#_Labor = 3
Cleaning_Labor$ = 10
Cleaning__Labor = Cleaning_#_Labor*Cleaning_Labor$

- Direct_Supervisory_&_Clerical_% = 0.15
- F&S_#_Labor = 1
- F&S_Labor$ = 15
- Filling_#_Labor = 4
- Filling_Labor = Filling_#_Labor*Filling_Labor$+Ingredient_Prep_Labor
- Filling_Labor$ = 10
- Final_Inspection_Labor = Unloading&Wash_Labor+Final_Insp_#_Labor*Final_Insp_Labor$
- Final_Insp_#_Labor = ROUND(Max_Output_per_Min/F_Insp_Eff/F_Insp_Speed+0.5)
- Final_Insp_Labor$ = 10
- Final_Packaging_Labor = FP_#_Labor*Final_Pack_Labor$+Final_Inspection_Labor+Cleaning__Labor
- Final_Pack_Labor$ = 10
- First_Inspectin_Labor = First_Insp_Labor$*First_Insp_#_Labor+Form&Seal_Labor
- First_Insp_#_Labor = ROUND(Max_Output_per_Min/First_Insp_Eff/First_Insp_Speed+0.5)
- First_Insp_Eff = 0.9
- First_Insp_Labor$ = 10
- First_Insp_Speed = 20
- Form&Seal_Labor = F&S_#_Labor*F&S_Labor$+Filling_Labor
- FP_#_Labor = 2
- F_Insp_Eff = 0.9
- F_Insp_Speed = 10
- Gravy_Prep_#_Labor = 1
- Ingredient_Prep_Labor = Gravy_Prep_#_Labor*Ing_Prep_Labor$+Warehouse_Labor
- Ing_Prep_Labor$ = 10
- Loading_Labor = Rework_Labor+Load_#_Labor*Loading_Labor$
- Loading_Labor$ = 10
- Load_#_Labor = ROUND(Max_Output_per_Min/Load_Eff/Load_Speed+0.5)
- Load_Eff = 0.9
- Load_Speed = 30
- Max_Output_per_Min = Pouches_per_Min
- Quality_Control_% = 0.15
- Retort_#_Labor = 2
- Retort_Labor = Loading_Labor+Retort_#_Labor*Retort_Labor$
- Retort_Labor$ = 15
- Rewk_#_Labor = ROUND(Max_Output_per_Min*(1-First_Insp_Yield)/Rewk_Eff/Rewk_Speed + 0.5)
- Rewk_Eff = 0.9
- Rewk_Speed = 10
- Rework_Labor = First_Inspectin_Labor+Rewk_#_Labor*Rework_Labor$
- Rework_Labor$ = 10
- Total_Hourly_Labor_Cost = Final_Packaging_Labor*(1+Direct_Supervisory_&_Clerical_%+Quality_Control_%)

Unloading&Wash_Labor = Retort_Labor+Unload_#_Labor*Unloading_Labor$
Unloading_Labor$ = 10
Unload_#_Labor = ROUND(Max_Output_per_Min/Unload_Eff/Unload_Speed+0.5)
Unload_Eff = 0.9
Unload_Speed = 40
Warehouse_Labor = WH_Labor$*WH_#_Labor
WH_#_Labor = 2
WH_Labor$ = 10

**ourly Raw Material Cost**

Beef = Target_Fill_Wt*Beef%*Beef$
Beef$ =
•2.00/28.3/16

Beef% = 0.3948
Bottom_Film_$_per_M = 0.71
Carrots = Target_Fill_Wt*Carrots%*Carrots$
Carrots$ = 0.65/28.3/16
Carrots% = 0.073
Carton$_per_Pouch = Carton_Unit_Cost/Pouches_per_Carton
Carton_Unit_Cost = 0.07
Case$_per_Pouch = Case_Unit_Cost/Pouches_per_Case
Case_Unit_Cost = 0.34
Expected_Form_&_Seal_Output = Form&Seal_Output
Filling_Mat_per_Min = Igredient_Prep_Mat*Pouches_Required_per_Min
Filling_Yield = 0.97
Film$_per_Min = Film$_per_Pouch*Expected_Form_&_Seal_Output/Form&Seal_Yield
Film$_per_Pouch = (Bottom_Film_$_per_M+Top_Film_$_per_M)/Pouches_per_Meter
Final_Inspection_Mat = Unloading_Mat
Final_Pack$_per_Pouch =
Carton$_per_Pouch+Case$_per_Pouch+Insert$_per_Pouch+Pallet$_per_Pouch
Final_Pack_Mat$_per_Min = Final_Inspection_Output*Final_Pack$_per_Pouch
First_Inspectin_Mat = Form&Seal_Mat
Form&Seal_Mat = Filling_Mat_per_Min+Film$_per_Min
Form&Seal_Yield = 0.98
Gravy = Target_Fill_Wt*Gravy%*Gravy$
Gravy$ = 0.15/28.3/16
Gravy% = 0.4292
Hourly_Raw_Material$ = Raw_Material$_per_Min*60
Igredient_Prep_Mat = Warehouse+Pouch_Ingredient_Cost/Ingred_Prep_Yield
Ingred_Prep_Yield = 0.95
Insert$_per_Pouch = Insert_Unit_Cost/Pouches_per_Insert
Insert_Unit_Cost = 0.23
Loading_Mat = First_Inspectin_Mat
Pallet$_per_Pouch = Pallet_Unit_Cost_2/Pouches_per_Pallet

- Pallet_Unit_Cost_2 = 10.0
- Peas = Target_Fill_Wt*Peas%*Peas$
- Peas$ = 0.85/28.3/16
- Peas% = 0.03
- Potato = Target_Fill_Wt*Potato%*Potato$
- Potato$ = 0.70/28.3/16
- Potato% = 0.073
- Pouches_per_Carton = 1
- Pouches_per_Case = 72
- Pouches_per_Insert = 72
- Pouches_per_Meter = 16.52893
- Pouches_per_Pallet = 2880
- Pouches_Required_per_Min = Expected_Form_&_Seal_Output/Filling_Yield-Reworking_Output
- Pouch_Ingredient_Cost = Beef+Carrots+Gravy+Peas+Potato
- Raw_Material$_per_Min = Final_Inspection_Mat+Final_Pack_Mat$_per_Min
- Retort_Mat = Loading_Mat
- Target_Fill_Wt = 233
- Top_Film_$_per_M = 0.71
- Unloading_Mat = Retort_Mat
- Warehouse = 0.0

**Production Schedule & Manufacturing Cost**

- Annual_Capital_Charge = Annual_Plant_Charge
- Annual_Labor_Cost = Total_Hourly_Labor_Cost*Hrs_per_Yr
- Annual_Output = Final_Packaging_Output*60*Hrs_per_Yr
- Annual_Raw_Material_Cost = Hourly_Raw_Material$*Hrs_per_Yr
- Annual_Total_Cost = Annual__Cost/(1-Overhead)*Overhead+Annual__Cost
- Annual_Utility_Cost = Hourly_Utility_Cost*Hrs_per_Yr
- Annual__Cost = Annual_Capital_Charge+Annual_Labor_Cost+Annual_Raw_Material_Cost+Annual_Utility_Cost
- Days_per_Week = 5
- Hrs_per_Shift = 8
- Hrs_per_Yr = Days_per_Week*Hrs_per_Shift*Shifts_per_Day*Weeks_per_Yr
- Overhead = .07
- Pouch_Cost = Annual_Total_Cost/Annual_Output
- Shifts_per_Day = 1
- Weeks_per_Yr = 48

**Utility**

- Air_Rate = 0.0004
- Cooling_Water_Rate = 0.0003
- Electric_Rate = 0.09
- F&S_Air = 1000

F&S_Cooling_Water_3 = 50
F&S_Electric = 20
Filling_Utl_1 = Fill_Electric+Gravy_Prep_Utl_1
Filling_Utl_2 = Gravy_Prep_Utl_2
Filling_Utl_3 = Gravy_Prep_Utl_3
Filling_Utl_4 = Gravy_Prep_Utl_4
Filling_Utl_5 = Gravy_Prep_Utl_5+Fill_Air
Fill_Air = 10
Fill_Electric = 10
Final_Packaging_Utl_1 = FP_Electric+Retort_Utl_1
Final_Packaging_Utl_2 = Retort_Utl_2
Final_Packaging_Utl_3 = Retort_Utl_3
Final_Packaging_Utl_4 = Retort_Utl_4
Final_Packaging_Utl_5 = Retort_Utl_5
FP_Electric = 10
Gravy_Prep_Utl_1 = Prep_Electric+Warehouse_Utl_1
Gravy_Prep_Utl_2 = Prep_Process_Water+Warehouse_Utl_2
Gravy_Prep_Utl_3 = Prep_Cooling_Water+Warehouse_Utl_3
Gravy_Prep_Utl_4 = Warehouse_Utl_4+Prep_Steam
Gravy_Prep_Utl_5 = Warehouse_Utl_5
Hourly_Air$ = Final_Packaging_Utl_5*Air_Rate
Hourly_Cooling_Water$ = Cooling_Water_Rate*Final_Packaging_Utl_3
Hourly_Electric$ = Electric_Rate*Final_Packaging_Utl_1
Hourly_Process_Water$ = Final_Packaging_Utl_2*Process_Water_Rate
Hourly_Steam$ = Final_Packaging_Utl_4*Steam_Rate
Hourly_Utility_Cost =
Hourly_Steam$+Hourly_Air$+Hourly_Cooling_Water$+Hourly_Electric$+Hourly_Process_Water$
Pouch_Form&Seal_Utl_1 = F&S_Electric+Filling_Utl_1
Pouch_Form&Seal_Utl_2 = Filling_Utl_2
Pouch_Form&Seal_Utl_3 = F&S_Cooling_Water_3+Filling_Utl_3
Pouch_Form&Seal_Utl_4 = Filling_Utl_4
Pouch_Form&Seal_Utl_5 = Filling_Utl_5+F&S_Air
Prep_Cooling_Water = 200
Prep_Electric = 5
Prep_Process_Water = 200
Prep_Steam = 500
Process_Water_Rate = 0.001
Retort_Air = 100
Retort_Cooling_Water = 10000
Retort_Electric = 15
Retort_Steam = 3000
Retort_Utl_1 = Pouch_Form&Seal_Utl_1+Retort_Electric
Retort_Utl_2 = Pouch_Form&Seal_Utl_2
Retort_Utl_3 = Pouch_Form&Seal_Utl_3+Retort_Cooling_Water
Retort_Utl_4 = Pouch_Form&Seal_Utl_4+Retort_Steam

- Retort_Utl_5 = Retort_Air+Pouch_Form&Seal_Utl_5
- Steam_Rate = 0.007
- Warehouse_Utl_1 = WH_Electric
- Warehouse_Utl_2 = 0.0
- Warehouse_Utl_3 = 0.0
- Warehouse_Utl_4 = 0.0
- Warehouse_Utl_5 = 0.0

- WH_Electric = 25

## APPENDIX F
## SpreadSheet for Beef Stew Fill Weight Design B

# Production Schedule

| | |
|---|---|
| Hours/Shift | 8 |
| Shifts/Day | 1 |
| Days/Week | 5 |
| Weeks/Year | 48 |
| Hours/Year | 1920 |
| | |
| Production Rate MRE Line | |
| Units/Minute | 102 |
| | |
| Avg Unit Fill&Seal/Hour | 4,651 |
| Avg Unit for Fill / Hour with reworl | 4,455 |
| Avg Unit FP Output Rate/Hour | 4,250 |
| Daily Unit Rate | 34,001 |
| Annual Output from Final Inspect | 8,242,671 |
| Annualized Unit Rate | 8,160,244 |
| Annual Requirement | 5,000,000 |
| Plant Utilization | 61.27% |

# Process Yield & Efficiency

| | Efficiency | Yield |
|---|---|---|
| Product Preparation Equipm. | 90.0% | 95.0% (yield of gravy system) |
| Filling Equipment | 95.0% | 97.0% (avg yield of product) |
| Horizontal Form & Seal Equipmei | 80.0% | 90.0% (yield of packaging material) |
| Pouch Packaging System | 76.0% | |
| First Inspection Equipment | 90.0% | 92.3% (% accepted pouches) |
| Rework System | 80.0% | 95.0% |
| Rack Loading Equipment | 90.0% | 100.0% |
| Retort Equipment | 90.0% | 100.0% |
| Rack Unloading Equipment | 90.0% | 100.0% |
| Final Inspection Equipment | 90.0% | 100.0% (% accepted pouches) |
| Final Packaging Equipment | 70.0% | 99.0% (% yield including qc samples tε |

| Process Design Capacity | Rated Capacity | Output Expected | |
|---|---|---|---|
| Product Preparation Equipment | 86.6 | 74.1 | pouches/min |
| Filling Equipment | 102.0 | 77.5 | pouches/min |
| Horizontal Form & Seal Equipmei | 102.0 | 77.5 | pouches/min |
| First Inspection Equipment | 113.3 | 71.6 | inspections/min |
| Rework System | 9.8 | 5.7 | |
| Rack Loading Equipment | 113.3 | 71.6 | pouches/min |
| Retort Equipment | 113.3 | 71.6 | pouches/min |
| Rack Unloading Equipment | 113.3 | 71.6 | pouches/min |
| Final Inspection Equipment | 113.3 | 71.6 | inspections/min |
| Final Packaging Equipment | 145.7 | 70.8 | pouches/min |

# Material Data Cost Sheet

| Formula | % Formula | Preparation Yield% | Cost/lb | Cost/Lb | Fat Cont% | Salt Cont% | Drained Wt. Yield% |
|---|---|---|---|---|---|---|---|
| 95 | 41.13% | 95.00% | $0.15 | $0.065 | 3.60% | 0.12% | |
| 87 | 37.66% | 95.00% | $2.00 | $0.793 | 0.65% | 2.36% | 85.00% |
| 49 | 21.21% | | | | | | 135.00% |
| 20.473538 | 8.86% | 95.00% | $0.70 | $0.065 | | | |
| 20.473538 | 8.86% | 95.00% | $0.65 | $0.061 | | | |
| 8.0529248 | 3.49% | 95.00% | $0.85 | $0.031 | | | |
| ========= | ========= | | | ========= | | | |
| 231 | 100.00% | | | $1.015 | | | |

| | | |
|---|---|---|
| Avg Target Fill Weight | [gram] | 231 |
| | [lb] | 0.510159 |
| | **Product Cost/Containe** | **$0.518** |

/laterial

| $/m | pouches/m | % yield | $/pouch |
|---|---|---|---|
| $0.71 | 16.528926 | 90.0% | $0.048 |
| $0.71 | 16.528926 | 90.0% | $0.048 |
| | | | ========= |
| | **Pouch Cost** | | **$0.096** |

| $/unit | pouch/unit | % yield | $/pouch |
|---|---|---|---|
| $0.07 | 1 | 99.00% | $0.074 |
| $0.34 | 72 | 99.00% | $0.005 |
| $0.23 | 72 | 99.00% | $0.003 |
| $10.00 | 2880 | 99.00% | $0.003 |
| | | | ========= |
| | **FP Packaging Cost** | | **$0.085** |

# Labor Cost Estimate

| | | Rate | Wages |
|---|---|---|---|
| Warehouse Labor | 2 | $10.00 | $20.00 |
| Gravy Prep Labor | 1 | $10.00 | $10.00 |
| Filling Labor | 1 | $10.00 | $10.00 |
| Packaging Labor | 1 | $15.00 | $15.00 |
| First Inspection | 6 | $10.00 | $60.00 |
| Rework Labor | 1 | $10.00 | $10.00 |
| Rack Loading | 4 | $10.00 | $40.00 |
| Retort Labor | 2 | $15.00 | $30.00 |
| Rack Unloading & Washing | 3 | $10.00 | $30.00 |
| Final Inspection Labor | 12 | $10.00 | $120.00 |
| Finished Product Packaging | 2 | $10.00 | $20.00 |
| Cleaning Labor | 3 | $10.00 | $30.00 |
| | ========= | ========= | =========== |
| Total Labor / Hr | 38 | | $395.00 |
| Annual Opperating Labor Cost | | | $758,400.00 |
| Direct Supervisory and Clerical l | 15.00% OL | | $113,760 |
| Quality Control | 15.00% OL | | $113,760 |
| | | | =========== |
| Total Annual Labor Cost | | | $985,920 |

| | | |
|---|---|---|
| Assumptions Labor: | sec/inspec | inspector |
| First Inspection Time | 3 | 5.7 |
| Second Inspection Time | 6 | 11.3 |
| | p/man/min | man |
| Rack Loading | 30 | 3.8 |
| Rack Unloading | 40 | 2.8 |
| | p/man/min | |
| Rework Labor | 10 | 1.0 |

# Capital Equipment

| | | |
|---|---|---|
| Warehouse Equipment | | $100,000.00 |
| Gravy Preparation Equipment | | $100,000.00 |
| Filling Equipment | | $150,000.00 |
| Horizontal Form Fill Seal Equipment | | $350,000.00 |
| First Inspection Equipment | | $10,000.00 |
| Rack Loading Equipment | | $40,000.00 |
| Retort Equipment | | $940,000.00 |
| Rack Unloading Equipment | | $40,000.00 |
| Final Inspection Equipment | | $10,000.00 |
| Final Packaging Equipment | | $300,000.00 |
| | | =========== |
| **Total Purchased Equipment (PEC)** | | $2,040,000.00 |
| Installation | 45.00% PEC | $918,000.00 |
| Instrumentation | 9.00% PEC | $183,600.00 |
| Piping | 10.00% PEC | $204,000.00 |
| Electrical | 10.00% PEC | $204,000.00 |
| Service Facility | 40.00% PEC | $816,000.00 |
| Engineering & Supervision | 33.00% PEC | $673,200.00 |
| | | =========== |
| **Total Direct Plant Cost (DPC)** | | $5,038,800.00 |
| Contingency | 25.00% DPC | $1,259,700.00 |
| | | =========== |
| **Fixed Capital Investement (FCI)** | | $6,298,500.00 |
| Working Capital | 15.00% TCI | $1,111,500.00 |
| | | =========== |
| **Total Capital Investement (TCI)** | | **$7,410,000.00** |

| | | |
|---|---|---|
| Assumptions Retort | | |
| Containers/Rack | 21 | |
| Rack/Crate | 27 | |
| Crate/Retort | 4 | |
| Retort Load [container/retort] | 2268 | |
| Retort Cycle Time [min] | 75 | |
| Retort Capacity [cont/min] | 30.24 | |
| Number of Retorts | 4 | |
| Cost one retort | $235,000.00 | |
| Budget cost one 1100 retort | $178,000.00 | rotating |
| Budget cost ome 1300 retort | $235,000.00 | rotating |

# Utility Cost Estimate

| Equipment | Gas [ft3/hr] | Water (P) [gal/hr] | Water (C) [gal/hr] | Steam [lb/hr] | Air [ft3/hr] | Electric [kW] |
|---|---|---|---|---|---|---|
| Warehouse | 0 | 0 | 0 | 0 | 0 | 25 |
| Gravy Prep | 0 | 200 | 200 | 500 | 0 | 5 |
| Filling | 0 | 0 | 0 | 0 | 10 | 10 |
| Packaging | 0 | 0 | 50 | 0 | 1000 | 20 |
| Retorting | 0 | 0 | 10000 | 3000 | 100 | 15 |
| FP Packaging | 0 | 0 | 0 | 0 | 0 | 10 |
| Total | 0 | 200 | 10250 | 3500 | 1110 | 85 |

| | Units | Usage | Cost/Unit | $/Hr |
|---|---|---|---|---|
| Natural Gas | [ft3/hr] | 0 | $0.0050 | $0.000 |
| Process Water | [gal/hr] | 200 | $0.0010 | $0.200 |
| Cooling Water | [gal/hr] | 10250 | $0.0003 | $3.075 |
| Steam | [lb/hr] | 3500 | $0.0070 | $24.500 |
| Compressed Air | [ft3/hr] | 1110 | $0.0004 | $0.444 |
| Electric | [kW] | 85 | $0.0900 | $7.650 |
| Energy Cost per Hour | | | | $35.869 |
| Annual Energy Cost | | | | $68,868 |

# Manufacturing Cost

| Direct Production Cost | | Annual Cost |
|---|---|---|
| Raw Materials | | $4,428,820 |
| Pouch Packaging Cost | | $857,593 |
| Carton & Case Cost | | $703,832 |
| Total Annual Labor Cost | | $985,920 |
| Utilities | | $68,868 |
| | | ============== |
| Total Direct Production Cost | | $7,045,034 |
| | | |
| **Fixed Charges** | | |
| Depreciation | 10.00% FCI | $629,850 |
| Maintenance and Repair | 6.00% FCI | $377,910 |
| Operating Supplies | 1.00% FCI | $62,985 |
| Local taxes | 4.00% FCI | $251,940 |
| Insurance | 1.00% FCI | $62,985 |
| Financing Cost | 9.00% TCI | $666,900 |
| Rent | | |
| | | ============== |
| **Total Fixed Charges** | | $2,052,570 |
| | | |
| Total Plant Overhead | 7.00% TMC | $684,766 |
| | | ============== |
| **Total Manufacturing Cost (TMC)** | | $9,782,370 |
| | | |
| **Manufacturing Cost per Packaging Unit** | | **$1.20** |

**Process Capability Index for The First Major Quality Characteristic: Beef Drained Weight**

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics: Target Value | Avg. Lower Spec. | Ind. Lower Spec. | Sample Size | Sample Data | Attribute Characteristics: Number of Defects | Sample Size | Estimated PCI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beef Dr. Wt. | 1 | 1 | 2 | | 73.95 | 68 | 56.7 | 17 | 55.4 | | | |
| | | | | | | | | | 51 | | | |
| | | | | | | | | | 48.8 | | | |
| | | | | | | | | | 45.6 | | | |
| | | | | | | | | | 41.8 | | | |
| | | | | | | | | | 54.4 | | | |
| | | | | | | | | | 41.8 | | | |
| | | | | | | | | | 45 | | | |
| | | | | | | | | | 46.2 | | | |
| | | | | | | | | | 47 | | | |
| | | | | | | | | | 52 | | | |
| | | | | | | | | | 43 | | | |
| | | | | | | | | | 45.4 | | | |
| | | | | | | | | | 47 | | | |
| | | | | | | | | | 43.8 | | | |
| | | | | | | | | | 55.3 | | | |
| | | | | | 73.95 | 5.95 | 17.25 | 4.488350935 | 49.4 | | | 1.281094122 |

## Process Capability Index for The First Critical Quality Characteristic: Net Weight

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Upper Spec Limit | Lower Spec Limit | Sample Size | Sample Data | Number of Defects | Sample Size | Estimated PCI |
| Net Weight | 1 | 1 | 2 | | 231 | 250 | | 17 | 229 | | | |
| | | | | | | | | | 241 | | | |
| | | | | | | | | | 234 | | | |
| | | | | | | | | | 223 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 233 | | | |
| | | | | | | | | | 233 | | | |
| | | | | | | | | | 231 | | | |
| | | | | | | | | | 235 | | | |
| | | | | | | | | | 235 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 239 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 230 | | | |
| | | | | | | | | | 230 | | | |
| | | | | | | | | | 234 | | | |
| | | | | | 231 | 19 | 19 | 4.570525777 | 229 | | | 1.385690321 |

| Process Capability Index for The Third Major Quality Characteristic: Salt Content | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | |
| | | | | | Target Value | Upper Spec Limit | Lower Spec Limit | Sample Size | Sample Data | Number of Defects | Sample Size | Estimated PCI |
| Salt Content | 1 | 1 | 1 | | 0.939415584 | 0.5 | 1.3 | 12 | 1.4 | | | |
| | | | | | | | | | 1.4 | | | |
| | | | | | | | | | 1.4 | | | |
| | | | | | | | | | 1.4 | | | |
| | | | | | | | | | 1.4 | | | |
| | | | | | | | | | 1.3 | | | |
| | | | | | | | | | 1.4 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 1.6 | | | |
| | | | | | | | | | 1.6 | | | |
| | | | | | | | | | 1.6 | | | |
| | | | | | 0.939415584 | 0.439415584 | 0.360584416 | 0.107308674 | 1.6 | | | 1.120084712 |

## Process Capability Index for The First Critical Quality Characteristic: Net Weight

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | Estimated PCI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Avg. Lower Spec. | Ind. Lower Spec. | Sample Size | Sample Data | Number of Defects | Sample Size | |
| Net Weight | 1 | 1 | 2 | | 231 | 226.7 | 212.6 | 17 | 229 | | | |
| | | | | | | | | | 241 | | | |
| | | | | | | | | | 234 | | | |
| | | | | | | | | | 223 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 233 | | | |
| | | | | | | | | | 233 | | | |
| | | | | | | | | | 231 | | | |
| | | | | | | | | | 235 | | | |
| | | | | | | | | | 235 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 239 | | | |
| | | | | | | | | | 238 | | | |
| | | | | | | | | | 230 | | | |
| | | | | | | | | | 230 | | | |
| | | | | | | | | | 234 | | | |
| | | | | | 231 | 4.3 | 18.4 | 4.570525777 | 229 | | | 1.34193168 |

## Process Capability Index for The Last Major Quality Characteristic: Vegetables Drained Weight

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | Estimated PCI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Avg. Lower Spec. | Ind. Lower Spec. | Sample Size | Sample Data | Number of Defects | Sample Size | |
| Vegetable Dr. Wt. | 1 | 1 | 2 | | 66.15 | 45.3 | 34 | 17 | 40.5 | | | |
| | | | | | | | | | 61.6 | | | |
| | | | | | | | | | 58.2 | | | |
| | | | | | | | | | 52.8 | | | |
| | | | | | | | | | 67.5 | | | |
| | | | | | | | | | 49.8 | | | |
| | | | | | | | | | 66 | | | |
| | | | | | | | | | 47.5 | | | |
| | | | | | | | | | 63.3 | | | |
| | | | | | | | | | 52.5 | | | |
| | | | | | | | | | 62 | | | |
| | | | | | | | | | 68 | | | |
| | | | | | | | | | 47 | | | |
| | | | | | | | | | 54 | | | |
| | | | | | | | | | 67.3 | | | |
| | | | | | | | | | 63 | | | |
| | | | | | 66.15 | 20.85 | 32.15 | 8.330105748 | 61.2 | | | 1.286498274 |

## Process Capability Index for The First Minor Quality Characteristic: Connective Tissue

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | Estimated PCI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Upper Spec Limit | Lower Spec Limit | Sample Size | Sample Data | Number of Defects | Sample Size | |
| Connective Tissue | 1 | 1 | 1 | | 4.80675 | 10 | | 17 | 2 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 1 | | | |
| | | | | | | | | | 1 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 2 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 2 | | | |
| | | | | | | | | | 1 | | | |
| | | | | | | | | | 2.5 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 1.5 | | | |
| | | | | | | | | | 1 | | | |
| | | | | | | | | | 2.5 | | | |
| | | | | | | | | | 2 | | | |
| | | | | | 4.80675 | 5.19325 | 5.19325 | 0.507299656 | 1 | | | 3.412348722 |

## Producibility Index

| | | Importance Ratio |
|---|---|---|
| Minimum Critical PCI: | 1.385690321 | |
| Geomean Critical PCI: | 1.385690321 | 5 |
| Minimum Major PCI: | 1.120084712 | |
| Geomean Major PCI: | 1.254564171 | 3 |
| Minimum Minor PCI: | 3.412348722 | |
| Geomean Minor PCI: | 3.412348722 | 1 |
| Average Overall PCI: | 1.481707748 | |

| | | |
|---|---|---|
| **Producibility Index** | **PCI Critical:** | **1.385690321** |
| | **PCI Major:** | **1.120084712** |
| | **PCI Minor:** | **3.412348722** |
| | **PCI Average:** | **1.481707748** |
| | **Manufacturing Cost:** | **$1.199** |

## APPENDIX G
## SpreadSheet for Ham Slice Pouch Design B

# Production Schedule

| | |
|---|---|
| Hours/Shift | 8 |
| Shifts/Day | 1 |
| Days/Week | 5 |
| Weeks/Year | 48 |
| Hours/Year | 1920 |
| | |
| Production Rate MRE Line | |
| Units/Minute | 60 |
| | |
| Avg Unit Fill&Seal/Hour | 2,924 |
| Avg Unit for Fill / Hour with reworl | 2,798 |
| Avg Unit FP Output Rate/Hour | 2,705 |
| Daily Unit Rate | 21,643 |
| Annual Output from Final Inspect: | 5,246,874 |
| Annualized Unit Rate | 5,194,405 |
| Annual Requirement | 5,000,000 |
| Plant Utilization | 96.26% |

## Process Yield & Efficiency

| | Efficiency | Yield | |
|---|---|---|---|
| Slicing Operation | 90.0% | 90.0% | (yield of gravy system) |
| Robot/Manual Fill | 95.0% | 99.0% | (avg yield of product) |
| Horizontal Form & Seal Equipme | 95.0% | 98.0% | (yield of packaging material) |
| Pouch Packaging System | 81.2% | | |
| First Inspection Equipment | 90.0% | 94.4% | (% accepted pouches) |
| Rework System | 80.0% | 95.0% | |
| Rack Loading Equipment | 90.0% | 100.0% | |
| Retort Equipment | 90.0% | 100.0% | |
| Rack Unloading Equipment | 90.0% | 100.0% | |
| Final Inspection Equipment | 90.0% | 99.0% | (% accepted pouches) |
| Final Packaging Equipment | 70.0% | 99.0% | (% yield including qc samples t |

| Process Design Capacity | Rated Capacity | Output Expected | |
|---|---|---|---|
| Product Preparation Equipment | 57.5 | 46.6 | pouches/min |
| Filling Equipment | 60.0 | 48.7 | pouches/min |
| Horizontal Form & Seal Equipme | 60.0 | 48.7 | pouches/min |
| First Inspection Equipment | 66.7 | 46.0 | inspections/min |
| Rework System | 4.2 | 2.6 | |
| Rack Loading Equipment | 66.7 | 46.0 | pouches/min |
| Retort Equipment | 66.7 | 46.0 | pouches/min |
| Rack Unloading Equipment | 66.7 | 46.0 | pouches/min |
| Final Inspection Equipment | 66.7 | 45.5 | inspections/min |
| Final Packaging Equipment | 85.7 | 45.1 | pouches/min |

# Material Data Cost Sheet

| Product Ingredient | Formula | % Formula | %yield | Cost/lb | Cost/Lb | Fat Cont% | Salt Cont% | Yield% |
|---|---|---|---|---|---|---|---|---|
| Ham | 150 | 100.00% | 90.00% | $1.70 | $1.889 | 4.83% | 2.06% | 85.00% |
| | ========= | ========= | | | ========= | | | |
| | 150 | 100.00% | | | $1.889 | | | |

| | | |
|---|---|---|
| Avg Target Fill Weight | [gram] | 150 |
| | [lb] | 0.3312721 |
| | **Product Cost/Containe** | **$0.626** |

Packaging Material

| | $/m | pouches/m | % yield | $/pouch |
|---|---|---|---|---|
| Top Film | $0.71 | 16.528926 | 98.0% | $0.044 |
| Bottom Film | $0.71 | 16.528926 | 98.0% | $0.044 |
| | | | | ========= |
| | **Pouch Cost** | | | **$0.088** |

| | $/unit | pouch/unit | % yield | $/pouch |
|---|---|---|---|---|
| Carton | $0.07 | 1 | 99.00% | $0.074 |
| Case | $0.34 | 72 | 99.00% | $0.005 |
| Inserts | $0.23 | 72 | 99.00% | $0.003 |
| Pallet | $10.00 | 2880 | 99.00% | $0.003 |
| | | | | ========= |
| | **FP Packaging Cost** | | | **$0.085** |

# Labor Cost Estimate

| | | Rate | Wages |
|---|---|---|---|
| Warehouse Labor | 2 | $10.00 | $20.00 |
| Ham Unpacking/Slicing | 2 | $10.00 | $20.00 |
| Filling Labor | 2 | $10.00 | $20.00 |
| Tiromat Operating Labor | 1 | $15.00 | $15.00 |
| First Inspection | 4 | $10.00 | $40.00 |
| Rework Labor | 1 | $10.00 | $10.00 |
| Rack Loading | 3 | $10.00 | $30.00 |
| Retort Labor | 3 | $15.00 | $45.00 |
| Rack Unloading & Washing | 2 | $10.00 | $20.00 |
| Final Inspection Labor | 7 | $10.00 | $70.00 |
| Finished Product Packaging | 2 | $10.00 | $20.00 |
| Cleaning Labor | 3 | $10.00 | $30.00 |
| | ========= | ========= | =========== |
| Total Labor / Hr | 32 | | $340.00 |
| | | | |
| Annual Opperating Labor Cost | | | $652,800 |
| Direct Supervisory and Clerical I | 15.00% OL | | $97,920 |
| Quality Control | 15.00% OL | | $97,920 |
| | | | =========== |
| Total Annual Labor Cost | | | $848,640 |

| | | |
|---|---|---|
| Assumptions Labor: | sec/inspec | inspector |
| First Inspection Time | 3 | 3.3 |
| Second Inspection Time | 6 | 6.7 |
| | | |
| | p/man/min | man |
| Rack Loading | 30 | 2.2 |
| Rack Unloading | 40 | 1.7 |
| | | |
| | p/man/min | |
| Rework Labor | 10 | 0.4 |

# Capital Equipment

| | | |
|---|---|---|
| Warehouse Equipment | | $100,000.00 |
| Slicer/Unpacking Equipment | | $100,000.00 |
| Filling Equipment: Robot | | $0.00 |
| Horizontal Form Fill Seal Equipment | | $350,000.00 |
| First Inspection Equipment | | $0.00 |
| Rack Loading Equipment | | $40,000.00 |
| Retort Equipment | | $705,000.00 |
| Rack Unloading Equipment | | $40,000.00 |
| Final Inspection Equipment | | $10,000.00 |
| Final Packaging Equipment | | $300,000.00 |
| | | =========== |
| **Total Purchased Equipment (PEC)** | | $1,645,000.00 |
| Installation | 45.00% PEC | $740,250.00 |
| Instrumentation | 9.00% PEC | $148,050.00 |
| Piping | 10.00% PEC | $164,500.00 |
| Electrical | 10.00% PEC | $164,500.00 |
| Service Facility | 40.00% PEC | $658,000.00 |
| Engineering & Supervision | 33.00% PEC | $542,850.00 |
| | | =========== |
| **Total Direct Plant Cost (DPC)** | | $4,063,150.00 |
| Contingency | 25.00% DPC | $1,015,787.50 |
| | | =========== |
| **Fixed Capital Investement (FCI)** | | $5,078,937.50 |
| Working Capital | 15.00% TCI | $896,283.09 |
| | | =========== |
| **Total Capital Investement (TCI)** | | **$5,975,220.59** |

| | | |
|---|---|---|
| Assumptions Retort | | |
| Containers/Rack | 21 | |
| Rack/Crate | 27 | |
| Crate/Retort | 4 | |
| Retort Load [container/retort] | 2268 | |
| Retort Cycle Time [min] | 75 | |
| Retort Capacity [cont/min] | 30.24 | |
| Number of Retorts | 3 | |
| Cost one retort | $235,000.00 | |
| Budget cost one 1100 retort | $178,000.00 | rotating |
| Budget cost ome 1300 retort | $235,000.00 | rotating |

# Utility Cost Estimate

| Equipment | Gas [ft3/hr] | Water (P) [gal/hr] | Water (C) [gal/hr] | Steam [lb/hr] | Air [ft3/hr] | Electric [kW] |
|---|---|---|---|---|---|---|
| Warehouse | 0 | 0 | 0 | 0 | 0 | 25 |
| Ham Slicer | 0 | 0 | 0 | 0 | 0 | 5 |
| Filling: Robot | 0 | 0 | 0 | 0 | 0 | 0 |
| Packaging | 0 | 0 | 50 | 0 | 1000 | 20 |
| Retorting | 0 | 0 | 10000 | 3000 | 100 | 15 |
| FP Packaging | 0 | 0 | 0 | 0 | 0 | 10 |
| Total | 0 | 0 | 10050 | 3000 | 1100 | 75 |

| | Units | Usage | Cost/Unit | $/Hr |
|---|---|---|---|---|
| Natural Gas | [ft3/hr] | 0 | $0.0050 | $0.000 |
| Process Water | [gal/hr] | 0 | $0.0010 | $0.000 |
| Cooling Water | [gal/hr] | 10050 | $0.0003 | $3.015 |
| Steam | [lb/hr] | 3000 | $0.0070 | $21.000 |
| Compressed Air | [ft3/hr] | 1100 | $0.0004 | $0.440 |
| Electric | [kW] | 75 | $0.0900 | $6.750 |
| Energy Cost per Hour | | | | $31.205 |
| Annual Energy Cost | | | | $59,914 |

# Manufacturing Cost

| Direct Production Cost | | Annual Cost |
|---|---|---|
| Raw Materials | | $3,361,644 |
| Pouch Packaging Cost | | $495,136 |
| Carton & Case Cost | | $448,025 |
| Total Annual Labor Cost | | $848,640 |
| Utilities | | $59,914 |
| | | ============== |
| Total Direct Production Cost | | $5,213,359 |
| | | |
| **Fixed Charges** | | |
| Depreciation | 10.00% FCI | $507,894 |
| Maintenance and Repair | 6.00% FCI | $304,736 |
| Operating Supplies | 1.00% FCI | $50,789 |
| Local taxes | 4.00% FCI | $203,158 |
| Insurance | 1.00% FCI | $50,789 |
| Financing Cost | 9.00% TCI | $537,770 |
| Rent | | |
| | | ============== |
| **Total Fixed Charges** | | $1,655,136 |
| | | |
| Total Plant Overhead | 7.00% TMC | $516,983 |
| | | ============== |
| **Total Manufacturing Cost (TMC)** | | $7,385,478 |
| | | |
| **Manufacturing Cost per Packaging Unit** | | **$1.422** |

**Process Capability Index for The First Critical Quality Characteristic: Net Weight**

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Upper Spec Limit | Lower Spec Limit | Sample Size | Sample Data | Number of Defects | Sample Size | Estimated PCI |
| Net Weight | 1 | 1 | 2 | | 150 | 180 | | 10 | 132 | | | |
| | | | | | | | | | 142 | | | |
| | | | | | | | | | 138 | | | |
| | | | | | | | | | 140 | | | |
| | | | | | | | | | 135 | | | |
| | | | | | | | | | 140 | | | |
| | | | | | | | | | 140 | | | |
| | | | | | | | | | 138 | | | |
| | | | | | | | | | 136 | | | |
| | | | | | 150 | 30 | 30 | 3.198958164 | 142 | | | 3.12601775 |

**Process Capability Index for The Last Critical Quality Characteristic: Pouch Defect**

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Upper Spec Limit | Lower Spec Limit | Sample Size | Sample Data | Number of Defects | Sample Size | Estimated PCI |
| Pouch Defect | 2 | 1 | 2 | | | | | | | 494 | 1000000 | 1.09799051 |

## Process Capability Index for The First Major Quality Characteristic: Ham Drained Weight

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics | | | | | Attribute Characteristics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Target Value | Avg. Lower Spec. | Ind. Lower Spec. | Sample Size | Sample Data | Number of Defects | Sample Size | Estimated PCI |
| Ham Drained Wt. | 1 | 1 | 2 | | 127.5 | 102.1 | 107.7 | 10 | 91 | | | |
| | | | | | | | | | 103 | | | |
| | | | | | | | | | 94 | | | |
| | | | | | | | | | 94 | | | |
| | | | | | | | | | 87 | | | |
| | | | | | | | | | 91 | | | |
| | | | | | | | | | 102 | | | |
| | | | | | | | | | 88 | | | |
| | | | | | | | | | 95 | | | |
| | | | | | 127.5 | 25.4 | 19.8 | 5.850925853 | 102 | | | 1.128026601 |

**Process Capability Index for The First Critical Quality Characteristic: Net Weight**

| Characteristics | 1. Variable<br>2. Attribute | 1. Stationary<br>2. Non-stationary | 1. Bilateral Specs<br>2. Unilateral Specs | 1. Symmetric Specs<br>2. Asymmetric Specs | Variable Characteristics<br>Target Value | Avg. Lower Spec. | Ind. Lower Spec. | Sample Size | Sample Data | Attribute Characteristics<br>Number of Defects | Sample Size | Estimated PCI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Net Weight | 1 | 1 | 2 | | 150 | 127.6 | 113.4 | 10 | 160 | | | |
| | | | | | | | | | 153 | | | |
| | | | | | | | | | 159 | | | |
| | | | | | | | | | 140 | | | |
| | | | | | | | | | 147 | | | |
| | | | | | | | | | 152 | | | |
| | | | | | | | | | 151 | | | |
| | | | | | | | | | 151 | | | |
| | | | | | | | | | 161 | | | |
| | | | | | 150 | 22.4 | 36.6 | 7.795297728 | 167 | | | 1.565046061 |

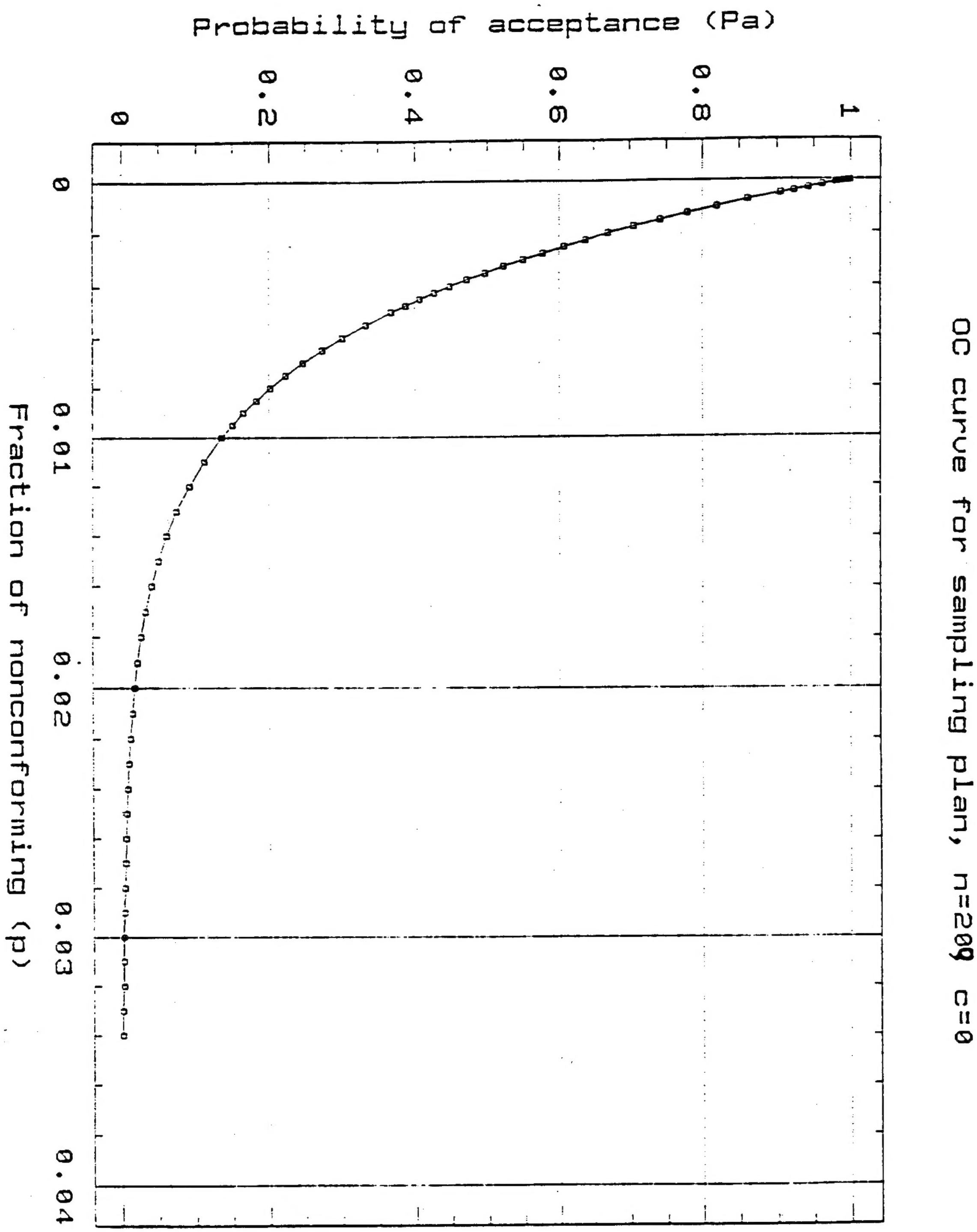
## Producibility Index

| | | Importance Ratio |
|---|---|---|
| Minimum Critical PCI: | 1.09799051 | |
| Geomean Critical PCI: | 1.852656963 | 5 |
| Minimum Major PCI: | 1.128026601 | |
| Geomean Major PCI: | 1.328688672 | 3 |
| Minimum Minor PCI: | | |
| Geomean Minor PCI: | | 1 |
| Average Overall PCI: | 1.635519006 | |

| | | |
|---|---|---|
| **Producibility Index** | **PCI Critical:** | **1.09799051** |
| | **PCI Major:** | **1.128026601** |
| | **PCI Minor:** | |
| | **PCI Average:** | **1.635519006** |
| | **Manufacturing Cost:** | **$1.422** |

# APPENDIX H

## Operating Characteristics Curve and Cross Reference Table for Pouch Defect Military Sampling Plan


OC curve for sampling plan, n=200 c=0
Probability of acceptance (Pa)
0
0.2
0.4
0.6
0.8
1
0
0.01
0.02
0.03
0.04
Fraction of nonconforming (p)

## Nonconforming Fraction vs. Acceptance Probability for Sampling Plan, n=200 c=0

| row | p | Pa | row | p | Pa |
|---|---|---|---|---|---|
| 1 | 0.000005 | 0.999 | 35 | 0.006000 | 0.301 |
| 2 | 0.000010 | 0.998 | 36 | 0.006500 | 0.273 |
| 3 | 0.000020 | 0.996 | 37 | 0.007000 | 0.247 |
| 4 | 0.000030 | 0.994 | 38 | 0.007500 | 0.223 |
| 5 | 0.000040 | 0.992 | 39 | 0.008000 | 0.202 |
| 6 | 0.000050 | 0.990 | 40 | 0.008500 | 0.183 |
| 7 | 0.000060 | 0.988 | 41 | 0.009000 | 0.165 |
| 8 | 0.000070 | 0.986 | 42 | 0.009500 | 0.150 |
| 9 | 0.000080 | 0.984 | 43 | 0.010000 | 0.135 |
| 10 | 0.000090 | 0.982 | 44 | 0.011000 | 0.111 |
| 11 | 0.000100 | 0.980 | 45 | 0.012000 | 0.091 |
| 12 | 0.000200 | 0.961 | 46 | 0.013000 | 0.074 |
| 13 | 0.000300 | 0.942 | 47 | 0.014000 | 0.061 |
| 14 | 0.000400 | 0.923 | 48 | 0.015000 | 0.050 |
| 15 | 0.000500 | 0.905 | 49 | 0.016000 | 0.041 |
| 16 | 0.000750 | 0.861 | 50 | 0.017000 | 0.033 |
| 17 | 0.001000 | 0.819 | 51 | 0.018000 | 0.027 |
| 18 | 0.001250 | 0.779 | 52 | 0.019000 | 0.022 |
| 19 | 0.001500 | 0.741 | 53 | 0.020000 | 0.018 |
| 20 | 0.001750 | 0.705 | 54 | 0.021000 | 0.015 |
| 21 | 0.002000 | 0.670 | 55 | 0.022000 | 0.012 |
| 22 | 0.002250 | 0.638 | 56 | 0.023000 | 0.010 |
| 23 | 0.002500 | 0.607 | 57 | 0.024000 | 0.008 |
| 24 | 0.002750 | 0.577 | 58 | 0.025000 | 0.007 |
| 25 | 0.003000 | 0.549 | 59 | 0.026000 | 0.006 |
| 26 | 0.003250 | 0.522 | 60 | 0.027000 | 0.005 |
| 27 | 0.003500 | 0.497 | 61 | 0.028000 | 0.004 |
| 28 | 0.003750 | 0.472 | 62 | 0.029000 | 0.003 |
| 29 | 0.004000 | 0.449 | 63 | 0.030000 | 0.002 |
| 30 | 0.004250 | 0.427 | 64 | 0.031000 | 0.002 |
| 31 | 0.004500 | 0.407 | 65 | 0.032000 | 0.002 |
| 32 | 0.004750 | 0.387 | 66 | 0.033000 | 0.001 |
| 33 | 0.005000 | 0.368 | 67 | 0.034000 | 0.001 |
| 34 | 0.005500 | 0.333 | | | |